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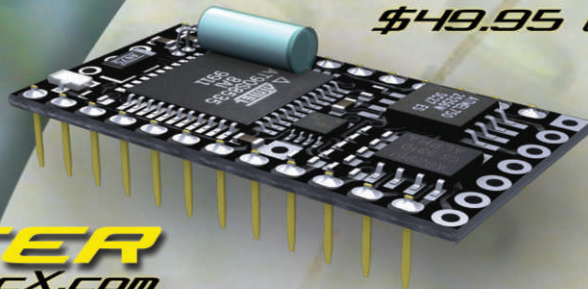


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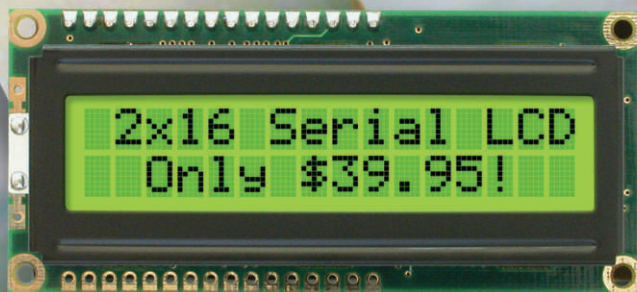
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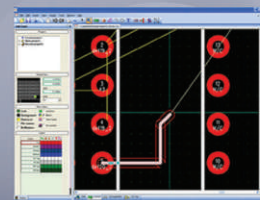
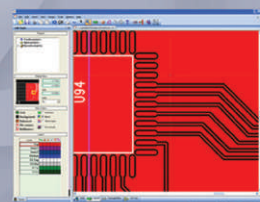
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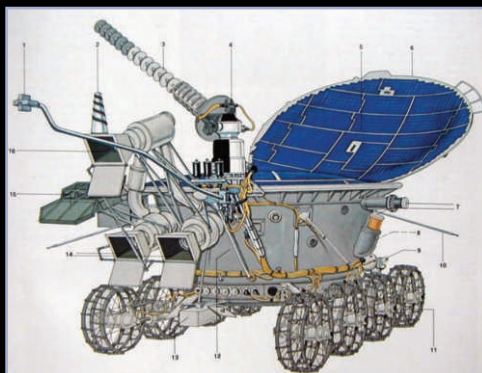
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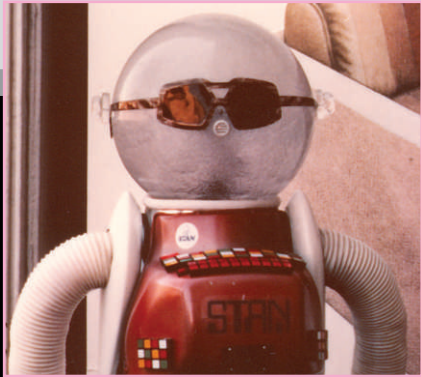
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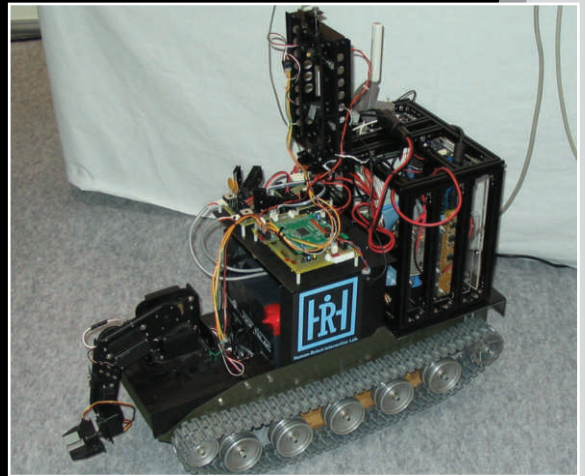
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Go undercover with Secret Agent Bot.

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# Mind / Iron



by Dan Danknick

**A**bstraction is the sharpest tool in an engineer's toolbox. There is no technical ability that quite matches the intellectual gymnastics of decomposing a problem to its constituent parts and then solving them, one at a time.

What separates good engineers from great engineers is the ability to return to first principles and work upwards in complexity. Even Ayn Rand said, "If you perceive a contradiction, check your premises" — and she was a philosopher!

In the field of robotics, we are constantly faced with choices about abstraction. This was quite evident, as nearly two dozen teams attempted to qualify their autonomous vehicles for the DARPA Grand Challenge last month in Southern California. The information from multiple sensors had to be integrated to form a model of the world. Using this model, goals were placed and decisions were derived. Approximations and noise abound, sensors fail, and the unexpected finds plenty of room. A good abstraction was the key to success.

Software is an ideal tool for implementing, testing, and tuning models of the world. (In fact, it is so good that, every year, more analog circuitry in consumer devices succumbs to clever digital design and faster signal processing — just look at how small your cell phone has become.)

If you've been working with robots for any length of time, you've certainly written a control program — starting with basic principles (reading sensors, driving motors) and gluing them together with a set of rules.

After convincing yourself that things operate as you expected, you're ready to enhance and extend — refining the world-

model that you've created.

Whenever I'm around other engineers, I try to be an intellectual sponge, sopping up the life experience that no textbook will ever explain.

When I worked for Canon's R&D group, my friend Bob Wadsworth was the target of much of my attention. Bob had written software for the Apollo guidance computer in the 1960s, so he'd done a lot of engineering in his life. He was, hands down, the master of abstraction — which was ideal in a software R&D group.

Each issue of *SERVO Magazine* strives to be a springboard for abstraction. Jack Buffington kicks off his monthly software column, directly disclosing the fundamentals of idea architecture. "Tetsujin Tech" is the first article in a series that will provide readers with information on the technologies needed for the Tetsujin competition. This month's article covers the basics of linear actuator selection and usage — a real help if you're going to compete in our weightlifting event, to be held this October. Roger Gilbertson explains how he used a complex metal to solve a simple problem on another planet. Pete Miles even dishes some advice on how to build a robot drummer for a rockabilly band. (Now that's abstract!)

When I correspond with authors during the development of an article, I always remind them to break the problem down into its component parts and explore the solution to each one. You may not be solving the same problem, but you'll likely face one or more of the basic elements during your development.

Even if you don't have access to a principal engineer where you work or go to school, it is my hope that the pages of *SERVO* are a worthy surrogate. **SV**

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## OUR PET ROBOTS

Guido  
Mifune

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# BIO-FEEDBACK

Dear SERVO:

First off, let me just say you rock! Words do not express how excited I am over this Tetsujin competition. This is quite literally the coolest possible thing I can imagine. My friend and I are currently formulating our strategy. As it happens, our employer manufactures strain gauge based isometric fitness equipment, so we have connections to strain gauge manufacturers already in the works. Plus, I really hate lifting stuff myself!

**Eric Scott**  
Team Nar Combat Robotics  
via Internet

Dear SERVO:

Your staff did a "rocking" review and story on the I-Cybie in *SERVO Magazine*, but I hope you've still got a little momentum left on this. How about doing an article on building your own cartridge programmer — even the cartridge? That would be super.

Here's a question for you. There have been quite a few webpages on doing the super I-Cybie mod to allow serial communication, but I haven't seen anyone using the IR on the front for programming. It seems to me that it would be a much easier way to go — no hardware mods at all.

**Mark Weston**  
via Internet

Dear SERVO:

I love *SERVO Magazine*, but what happened to Table 1 in "Cutting Edge Robotics: Part 2," in the February issue? I can't find it.

**Wade Smith**  
Rockford, IL

*It was overlooked during production, but we have placed it on our website for download ([www.servomagazine.com](http://www.servomagazine.com)).*

— Editor Dan

Dear SERVO:

Another great issue! You guys do a hell of a job with such a small staff. Graphic design is great, typos are at a minimum, editorial is great, and the ads

are just as interesting. Good job!

When do we get to see Guido and Mifune?

**Pierson Holcombe**  
via Internet

Dear SERVO:

Both my husband and I are avid readers. (I'm mystery/cooking/child-rearing and he's robotic/data chip/kayaking.) I do, however, want to have an idea of what my husband is happily prattling on about, so I picked up a copy of *SERVO* from his nightstand and — viola!

Most of it was easy to understand and incredibly interesting. I especially enjoyed "Robytes" — not just the information, but also Dave Calkins' witty writing style. If you promise not to tell, I may sneak a peek at his next issue!

**Misty Walker**  
via Internet

Dear SERVO:

I love *SERVO*. May I ask if you can indicate some sort of cost on projects? I am a beginner at the age of 54 and, while electronics were easy in high school, it has been awhile. I am currently working on a robotics project. The design is a pre-war Christie tank. I want to eventually computerize it and add a hand and arm. I have to start learning at the bottom.

Thanks for a wonderful magazine.

**Dave**  
via Internet

*In last month's "Geerhead" column, credit to Dale Wheat was inadvertently left off of the photo of 6-Pack. Therefore, we are sending him a six pack. — Editor Dan*

## got bot?

If so, then send 'em in. Show off your bot building abilities in "Menagerie," *SERVO's* showcase for the robotics hobbyist. Whether it rivals Asimo, aspires to be Electro, or simply looks cool in your living room, send us a write-up and a photo to [menagerie@servomagazine.com](mailto:menagerie@servomagazine.com) and we'll make you famous — sort of ...

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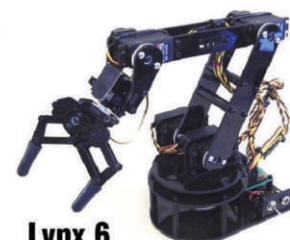
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The Japanese call it Tetsujin — Iron Man. This groundbreaking competition combines both brains and brawn. Tetsujin 2004 presents the ultimate challenge: Produce a powered, articulated exoskeleton to assist a human operator in lifting weights. Teams will compete against the clock and each other in this robotic showdown!

Held at the Santa Clara Convention Center, this world class competition — sponsored by *SERVO Magazine* — spotlights this emerging technology in the robotics industry, which has applications ranging from national defense improvements to new mobility for the disabled.

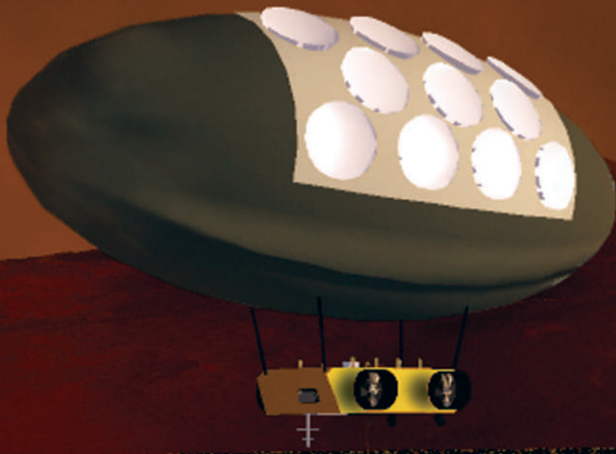
Teams for the competition are welcome from all sectors. Now is the time to gather your friends and co-workers and begin imagining. Answer the challenge of Tetsujin 2004! The earlier your team registers for the competition, the longer you will have to create and develop your entry.

Visit the *SERVO Magazine* website, click on the Tetsujin link, and sign up today. Complete rules, registration forms, and FAQ are available.

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*Enter the competition today!*





# Robots Rampage Across *the* Planets

by Dr. Ralph Lorenz

Image by Mark Robertson-Tessi and Ralph Lorenz

## Roaming on the Moon

While it was 1997's little Sojourner rover on the Mars Pathfinder that captured the public imagination, it is easy to forget — especially in the US — that the history of robots on planets goes much further back.

In 1970, the Soviet Union landed a rover on the Moon. The solar-powered Lunokhod 1 was equipped with eight

independently driven wheels and several cameras. About the size of a bathtub, it drove about six miles and could climb 16-inch high obstacles. Its successor, Lunokhod 2, was launched in 1973 and lasted four months, during which it drove over 20 miles. Between them, they took tens of thousands of TV pictures, relaying them at 3-20 seconds per frame (not frames per second!) and hundreds of panoramic images, as well as taking hundreds of soil hard-

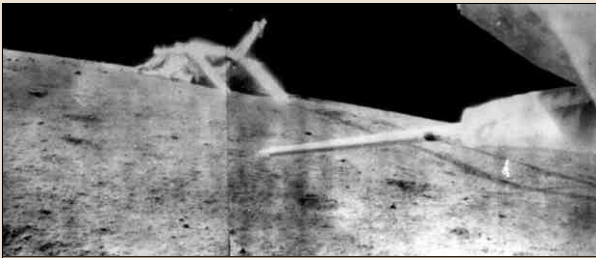
ness measurements.

The Mars Exploration Rovers (MERs) — Spirit and Opportunity — which are presently on the Red Planet, are each a hefty 200-odd kg, but Lunokhod would crush them to dust in a Battlebot deathmatch! Lunokhod 1 weighed three quarters of a ton! Its wire-mesh wheels — 51 cm in diameter — could climb over MER.

The Lunokhod vehicles lacked onboard intelligence — they were driv-

Heroes of the Soviet Union — Ground controllers drive Lunokhod 1 on the Moon's surface. Note the fans on the monitors — these things dissipated a lot of heat! Image courtesy of OAO VNITTransMash/Rover Company Limited.





The view back from Lunokhod 1 to the Luna 17 lander that delivered it. Image Processed by Ted Stryk.



View from Lunokhod 1 cameras. Image processed by Ted Stryk.

en by controllers on Earth with the aid of two video cameras. This kind of remote control (teleoperation) is not too difficult for operations on the Moon; the propagation time of signals at the speed of light introduces a delay of only a second or two into the control loop, so operators can guide the vehicle around with a little practice and care. A fun robotics project might be to set up a microcontroller to delay controller inputs, simulating this sort of delay — at first you crash a lot!

The roof of the Lunokhod carried a laser retroreflector — still used to measure precisely the distance from the Earth to the Moon, monitoring both continental drift and changes in the Moon's orbit. Lunokhod covered 20 m on the first day and 197 m in the first

week. (Spirit only just stepped off its lander, nine days after touchdown.) The reason for this is the propagation delay — it takes light between five and 20 minutes to reach Mars — far too long to “joystick” a vehicle around. Every hazard must be identified and planned around before commands are sent. Mars rovers require a lot of onboard autonomy; if a wheel gets stuck, the motor would burn out long before a controller on the ground could turn the motor off.

## The First Rover on Mars — 26 Years Before Sojourner

Sojourner was not even the first mobile robot on Mars — although it was the first known to have worked after landing. In 1971, the first Russian Mars landers (2 and 3) carried a dinky little gadget (PROP-M — a Russian abbreviation for Surface Evaluation Instrument) that walked on two flat feet. If it bumped into a rock, it would back up, turn, and start to move forward again, like the most primitive toy robots today. Unfortunately, Mars 2 crashed (becoming the first man-made object on Mars) and Mars 3 seems to have landed during a dust storm and was presumably knocked over by the fierce Martian winds; contact was lost 20 seconds after touchdown. PROP-M weighed 0.7 kg and used a 27 V power supply from the lander, driving itself with a 120 mA motor. The tether was

15 meters long.

The 1976 Mars Viking landers manipulated their local environment with a robot arm, with which it acquired soil samples for analysis in an onboard chemistry lab. Robot arms were even used 10 years prior to that by the US Surveyor landers on the Moon. These were robotic precursors to the Apollo landings, designed to test the ability of the lunar soil to take the weight of a spacecraft — it was feared that the lunar soil might be too soft and a lander might sink without a trace.

As well as soft-landing and taking pictures, these spidery landers used an arm to dig small trenches. By measuring the motor current needed to dig and observing the steepness of the walls of the trench, scientists could figure out the mechanical properties of the soil. Happily, the soil was firm enough to support vehicles, as Lunokhod and the Apollo Lunar Rovers demonstrate.

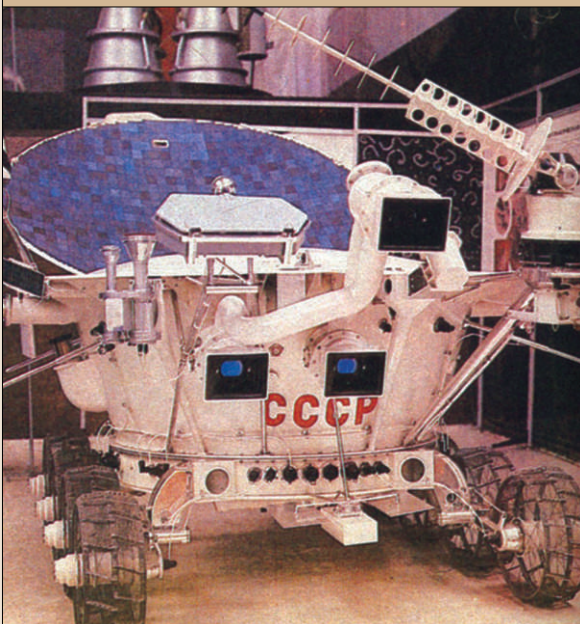
## Bounding on Phobos

The Soviets had another couple of attempts with roving robots around Mars. PROP-F — a 40 kg, self-contained, spherical spacecraft — contained a battery, radio system, and science instruments. It would “flip” itself off the ground with spidery arms. In the tiny gravity of potato-shaped Phobos — Mars' largest moon — it would soar 30-40 m in slow-motion to a new spot, where it would repeat its experiments. It was to be deposited on that moon by the Phobos spacecraft — a massive orbiter which would relay its signals to Earth.

Unfortunately, Phobos 1 failed en route to Mars (due to an operator error) and Phobos 2 was lost just before it arrived at Phobos.

An even smaller, 1 kg asteroid

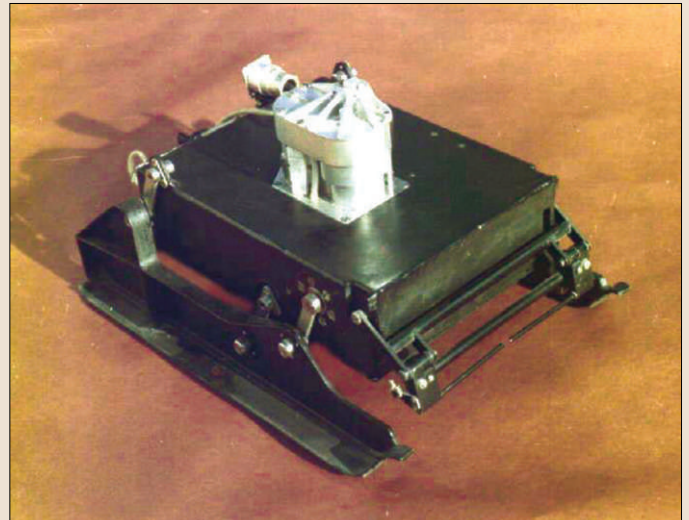
Lunokhod 2 — With its lid open, the solar panels are visible. Note the semitransparent wire mesh wheels and the black glashields on the forward-pointing drive cameras. Image courtesy of OAO VNITTransMash/Rover Company Limited.







View from Lunokhod 2 cameras. Image processed by Ted Stryk.



**Prop-M** — The first rover on Mars (though it probably didn't get to drive). Much like a modern Sumobot, it would waddle forward on long "feet," taking soil measurements with a penetrometer (the white box on top), until it bumped into a rock, which it would sense with the touchswitch bars at its front, causing it to back up and turn. Image courtesy of OAO VNITTransMash/Rover Company Limited.

rover, called MUSES-CN, was planned for the Japanese mission MUSES-C, which will rendezvous with an asteroid in 2005 to acquire some asteroidal material. This material would be gathered and returned to Earth by shooting a pellet at the asteroid surface to kick up dirt from the surface, which it would catch in a large funnel attached to the return capsule. This mission had also been planned to deploy a tiny NASA-supplied micro-rover (the "N" in -CN), but NASA budget constraints eliminated this project.

The Beagle 2 lander, built in Britain, carried a "mole" called PLUTO (PLANetary Underground TOol). This is a 340 g, pointed titanium cylinder, about 20 mm in diameter and 280 mm long. Inside is a spring with a weight — or "hammer." The spring can be wound up slowly by an electrical motor — when released, it accelerates the hammer forward to hit an end stop. Because the cycle is asymmetric — a long, slow stroke back and a rapid one forward — the soil doesn't grip the body of the mole quite the same way in either direction, so the mole drives itself forward. Sadly, Beagle 2 — last seen sailing towards Mars after release from the Mars Express mother ship — was lost without trace.

Like the Viking landers of the 1970s, this mission could last for years. Amateur roboticists face the same challenges as spacecraft engineers — in the end, power is everything. What killed Mars Pathfinder was the deep cycling and, ultimately, failure of its battery as it struggled to store enough energy to keep warm during the bitterly cold Martian night. European scientists also are planning a successor to Beagle 2, perhaps a rover carrying several moles.

On one of Jupiter's moons — Europa — an ocean of liquid water lurks beneath an ice crust of about 10 miles in thickness. Since life, as we know it,

needs liquid water, Europa beckons as a place to explore for signs of life. If life ever existed on Europa, there is probably life all over the galaxy, but how do we get through 10 miles of ice? One idea — the so-called cryobot — is a robot probe that melts its way through the ice with nuclear power. As a little bit of ice below the probe melts (or, in Europa's vacuum, sublimates to gas), the probe will settle a bit lower, and so on. Experience using this technique to drill through ice caps suggests that the hole

The PROP-F lander for Phobos, seen during tests on Earth. To the left, the transfer cradle has been detached and the lander is taking measurements before using its wire arms to flick itself to a new location. Image courtesy of OAO VNITTransMash/Rover Company Limited.

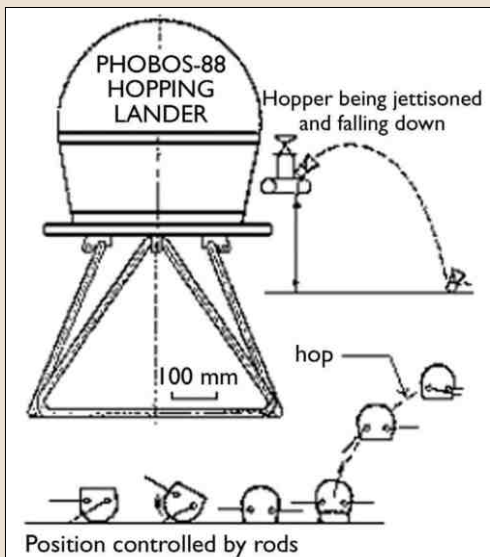


## What of the Future?

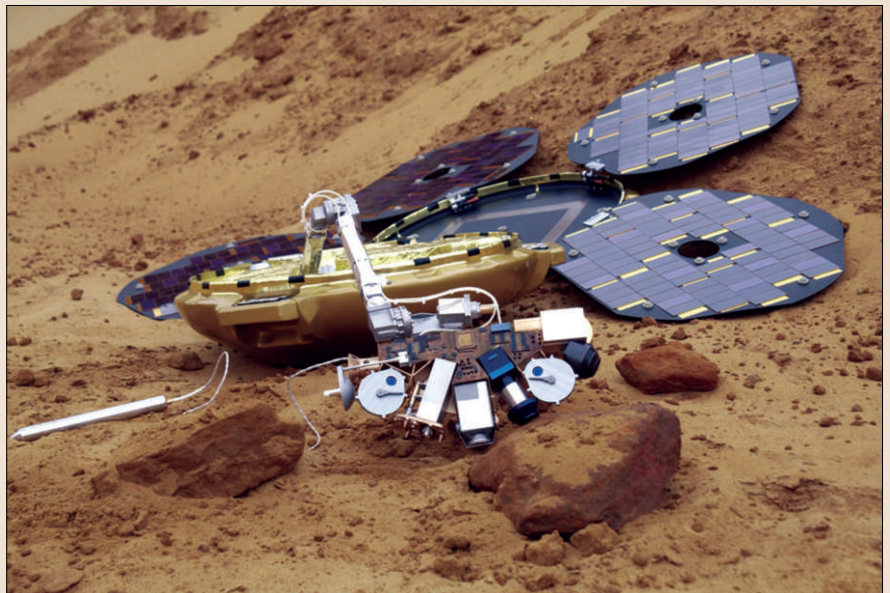
NASA plans a 2009 launch of a Mobile Science Laboratory — a nuclear-powered rover for the Martian surface.



# Robots Rampage Across the Planets



Principle of operation of PROP-F — Everything happens in slow-motion in the tiny gravity of Mars' moon, Phobos, which is probably a captured asteroid. Image courtesy of OAO VNITTransMash/Rover Company Limited.



The Beagle 2 lander — It was supposed to survey the surface of Mars. The mole has been deployed from a tube on the robot arm (the "paw" in foreground, carrying scientific instruments) and is inching its way across the surface to the left. All Rights Reserved Beagle 2.

will seal itself up and shearing in the slowly flowing ice layers would snap a cable.

So, the probe would have to communicate by radio, through the ice. Ten miles of ice is a tall order, so it would have to leave little transponder pucks behind every few hundred meters to boost the signal.

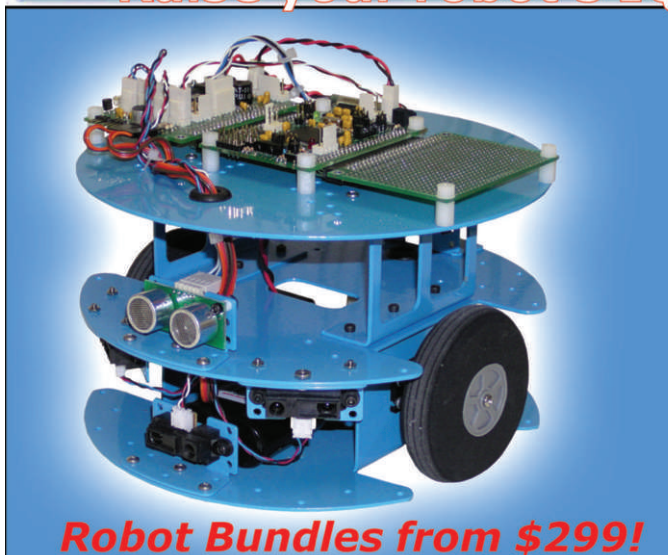
It is difficult to get to Europa — which lies deep in Jupiter's gravity well — so a great deal of rocket power is needed to reach there and even more

is required to soft-land. Worse, the onslaught of Jupiter's powerful radiation belts is fearsome — even the toughest rad-hard electronics the space industry can come up with would only last a month.

Perhaps more likely than probing Europa is a robot exploration of one of Saturn's moons, Titan. This giant, icy satellite (larger than the planet Mercury) is to be the target of the NASA-ESA Cassini mission, which will drop a parachute-borne probe —

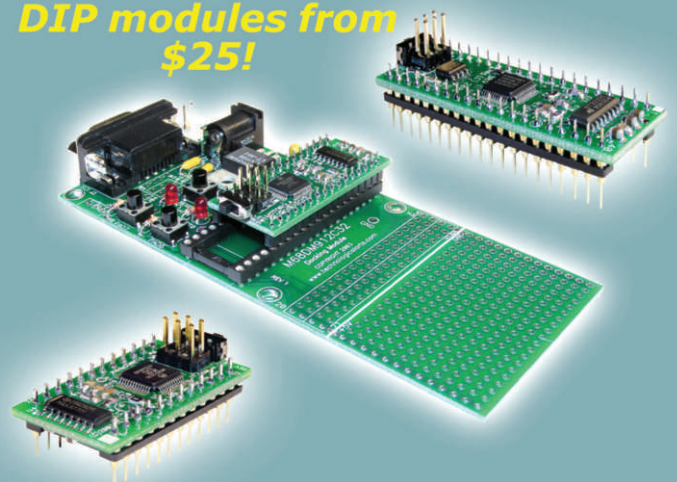
named Huygens — onto Titan in January 2005. Titan is unique in that it has a thick nitrogen atmosphere — much like ours, only thicker, colder, and with methane instead of oxygen and water vapor. The combination of an atmosphere four times denser than ours and gravity as weak as our own Moon's (1/7 of Earth's) makes Titan an ideal place to fly. If you could take a radio-controlled helicopter to Titan, it could hover using 38 times less power than it would need on Earth! A helicop-

## Raise your robot's IQ with Motorola's 9S12!



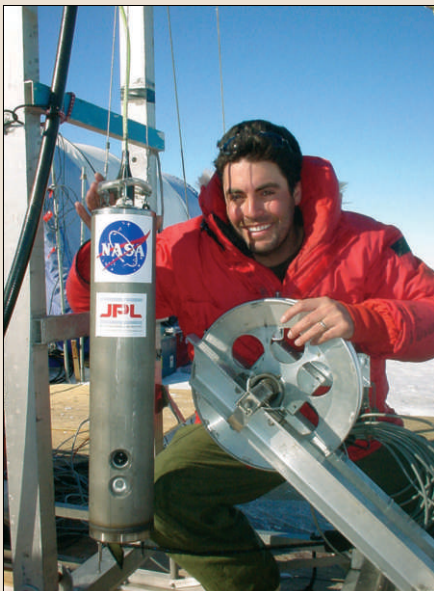
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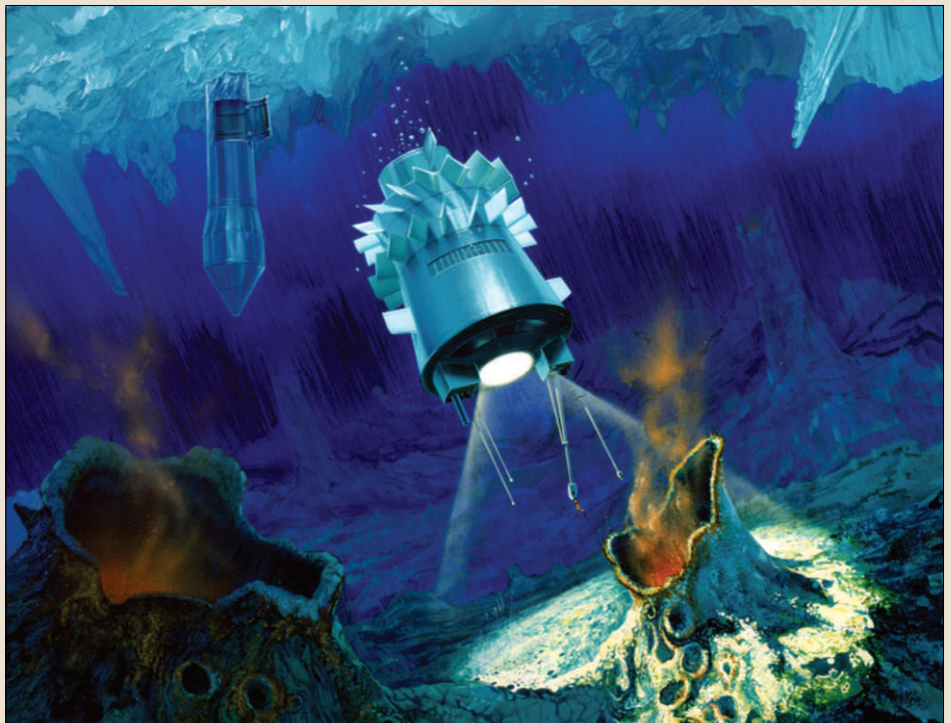


[www.technologicalarts.com](http://www.technologicalarts.com)





JPL engineer Dr. Alberto Behar, photographed during the testing of a "cryobot," a probe that might melt its way down through the ice crust of Europa or the polar cap of Mars. Photo courtesy of NASA/JPL.



A hydrobot — a subsurface ocean explorer which could be released into Europa's ocean from the cryobot. NASA/JPL

ter is great for landing at designated spots — scientists are interested in sampling the organic chemicals on Titan's surface, which may represent early steps in chemical evolution towards life.

Another possibility is using an airship or blimp, which could be driven over target sites employing thrusters to push itself down or, more likely, (since the surface might be sticky) lowering a sampling device on a tether

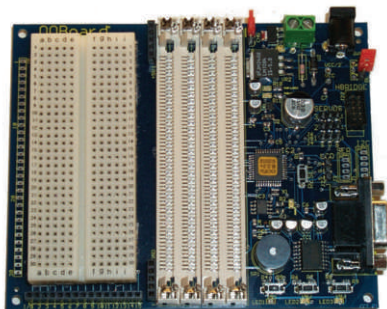
down to the surface. An artist's impression of such an airship (courtesy of Mark Robertson-Tessi and Ralph Lorenz) can be seen in the title box of this article.

The challenges of designing and operating robots on other planets are formidable, but many of the problems are just the same ones facing hobbyists in the garage — and that may be where

many of our solutions come from. **SV**

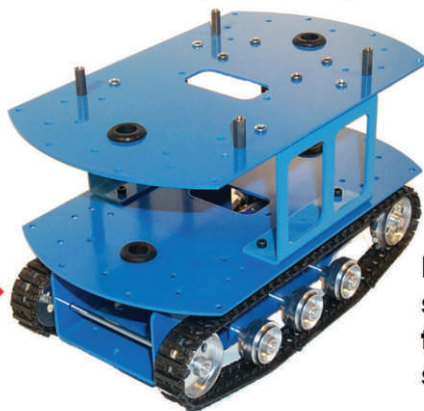
### A Quick Note ...

*The author thanks Dr Andrew Ball, an expert on the Russian space program, who teaches at the Open University in Milton Keynes, UK, for his assistance in locating useful reference material.*



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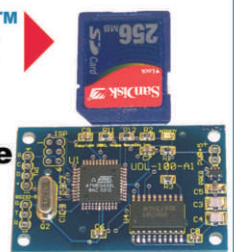


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## The Young and the Robotic



In the Stands: (left to right) Allyson Brown, Katie MacKenzie, Shelby Weston, Mackenzie Bartz, Bethany Yollin, and Jackie Thomas.

### *Robotic kids — a future with promise.*

When I was 12 years old, my biggest accomplishment was having memorized every line from every episode of *Star Trek*.

The kids you're about to meet surpass that achievement — and my expectations — with their robotics and the values they have learned from it.

These youngsters are good examples of the results that high school robotics programs can bring. Robotics is a great teaching tool for raising bright, well-equipped scientists, mathematicians, engineers, and general problem solvers.

Let's meet these young people now, starting with...

### Ladies First

*Let's have that bio, Katie!*

Katie Mackenzie, 14, attends Lake Oswego High School in Lake Oswego,

OR. Her favorite subjects are math and history. She enjoys math because of its relationship to engineering, which she is very interested in.

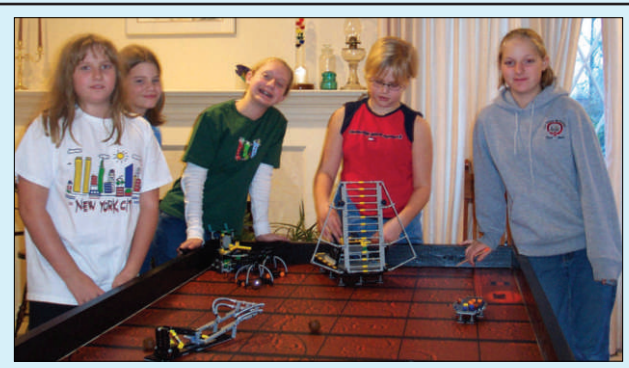
Katie is curious about the history of our world's technological evolutions. She likes most of her classes and thinks vegetables aren't too bad, either. Katie also likes popcorn — her favorite food.

Katie believes students should invest themselves in their schoolwork because it is so important to their futures.

### Katie Builds Bots

Katie began her robotics career in Lake Oswego Junior High at 13 years of age with a

The Girls' Team: (left to right) Bethany Yollin, Shelby Weston, Allyson Brown, Mackenzie Bartz, Katie MacKenzie.





basic robotics class. After school classes were available, which Katie eventually joined. The next year, she became part of an all-girl robotics team.

Katie thrives on robotics, applying "big kid" LEGOs to problem solving; the result is her robots. Here's how the process works: She takes a box — sort of like a mini-computer (LEGO's Robotic Command Explorer or RCX) — and tells it to undertake certain tasks. She tells her RCX these things through programming, using the software on her computer.

Next, she builds around this box using LEGOs. These extensions may be arms or other tools that the robot is programmed to use. She can make cars, bug-like robots, and all kinds of things. LEGO materials supply ample parts and pieces, so a young builder like Katie can construct almost anything she imagines (or pretty close to it).

If her task is to make a robot that can follow a straight line, she can make a bot which performs that activity by using just the right combination of LEGOs and programming.

## Learning Lessons, Challenging Competitions

Roboticians like Katie learn right away that not all things work according to formula, even with LEGOs. The software can be

challenging and even LEGOs don't always cooperate. The pieces don't always fit together, even when they're supposed to!

After those challenges come the competitions, where robots and/or builders complete a variety of tasks in a limited amount of time. Roboticians like Katie learn teamwork, which helps them compete. They learn dedication and they walk away with a treasured experience.

Katie has competed in the First LEGO League competitions and looks forward to perhaps assisting her coach with next year's team. She claims she's no whiz kid in robotics yet, but loves learning about robots, using what she learns in other subjects, and entertaining herself, too.

Katie is looking forward to events like the Pacific Northwest FIRST Robotics Competition at the Memorial Coliseum in Portland, OR (March 4-6) and the East Coast LEGO "freak."

*Here's a mental image for you!*

When I asked Katie to share an interesting memory from her competitions ...

They were at the end of the regional competition when teams were receiving participation ribbons. When it was her team's turn to be awarded, the host of the event asked about the team's uniforms. You see,

Katie's team was called the Kung Fu Robots and they all wore the Kung Fu outfits their moms provided.

Katie, being the oldest, spoke on behalf of the group. It turns out that they got the idea from the song, "Kung Fu Fighting," which she began to sing. The host for this event was surprised that these young children would be familiar with such an "old" song. Katie responded, "Everyone knows that song — it's classic. Come everyone — sing with us!" Katie, her team, and the crowd started singing the nostalgic 70s song together.

I hope someone had a video camera!

## Incarnation Academy

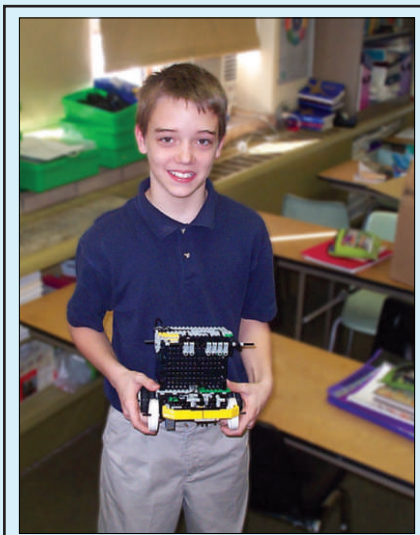
Two young men from Incarnation Academy, PA, represent the guys in this story.

### Up First, Andy

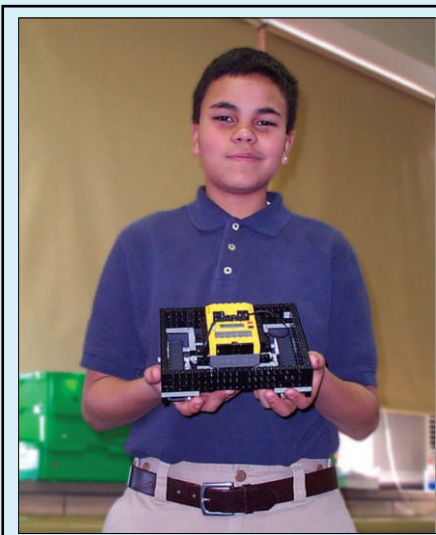
Andy Geisler is a sixth grader who enjoys basketball and baseball, but not writing. It made me laugh instantly to hear that. Andy got started with robotics early — in the fourth grade. Whew, that is young!

Andy's initial exposure led to further involvement in the fifth grade. Now, he is gearing up to full speed, enjoying both programming and building robots. According to Andy,

Andy Geisler with one of his robots.



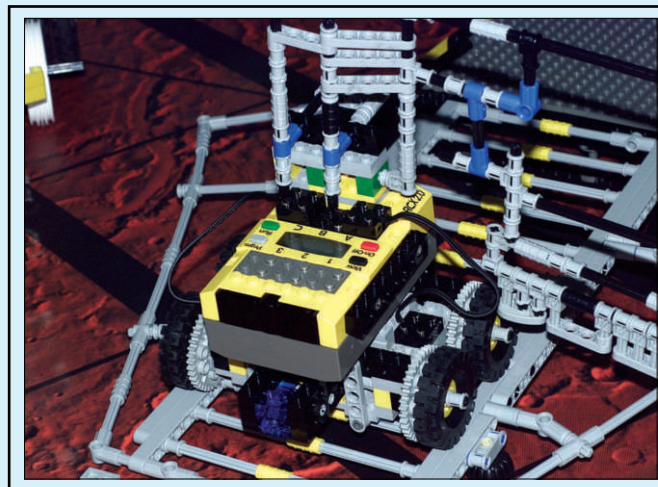
Brian Benny with one of his builds.



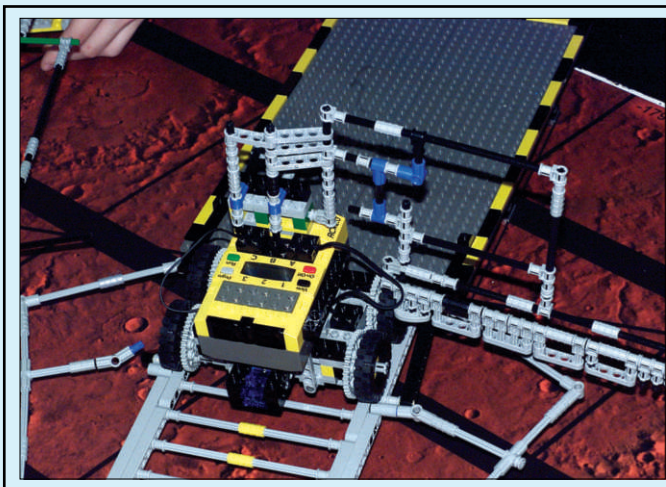
Brian (left) with Andy, holding their robotic creations.







One of the 'bot builds that got Andy and Brian hooked.



A line follower — on a track?!

building them was the part that really got him hooked.

## Resources You'll Find at the Robotics Academy Website

The Carnegie-Mellon Robotics Academy website has resources for parents, children, teachers, and other builders, even those who don't attend the competitions. Learning materials include Carnegie's Robotics Educator series on CD-ROM.

Series highlights include the complete robotics curriculum on a single CD-ROM, Robotics Explorer robotics exercises, C-based robot programming, and a robotics camp on a disk. All help to teach math, science, and engineering using robotic LEGO kits. You can preview the CDs online, too.

The Academy site will introduce you to LEGO Mindstorms robot construction products and to resources the Academy has available when you or your child is ready for camps, competitions, and even college-age robotics activities.

Additional links introduce young roboticists to Carnegie-Mellon's Robotics Institute. This peek at the adult world of robotics will help fascinate your child and provide assurance that there is more room to grow in robotics as they grow.

Though not fully introduced here, other major universities across the country have robotics programs, as well, including Indiana University, Johns Hopkins, and Cal Tech.

*See the resource list for the web link.*

Andy's current project is a four-wheel job with two motors at the back and both touch and rotational sensors. Adorned with many parts, the four wheeler can lift other objects with one attachment and push things around with another.

As with the program at Katie's school, Andy's robots are all LEGO based, which are provided by the school.

## Award Winning Designer

Another of Andy's robots won an award for exemplary design at a competition. It used an attachment and a touch sensor, which compel the robot to fling a ball into a small compartment.

Incarnation Academy competes against other teams at competitions sponsored by Carnegie-Mellon University. Competition involves three rounds with several teams competing. Roboticists must accomplish as much as they can within a limited time.

## Is it Work or Play?

Andy, his teammates, and fellow students learn engineering, math, programming, and problem solving from robotics. Andy wants to be an engineer some day. You can hear a certain confidence in his voice when he makes this assertion. Perhaps he really has already made up his mind.

## Next Up, Brian

Another young man from Incarnation, Brian Benny, is a 14-year-old eighth grader who likes robotics and basketball, but doesn't like some vegetables. At 12, Brian had just entered middle school when it began offering an after school robotics program.

Robotics was challenging for Brian in the beginning. Older and wiser now, Brian has advanced and is able to understand much of what he is taught, though he admits to being a little slow yet with the programming.

## Robotics Helps with Other Classes

Robotics involves ratios — for determining gear ratios — which helps with math; the math, in turn, helps with robotics. How does this apply?

One of Brian's robots is made of an RCX, four wheels, and two motors. It uses a 5-to-1 gear ratio — geared for power! It has a joist attachment that helps it reach places it can't get to on its own.

It has another gear system that lets Brian's robot go from wheels to treads. One of his robots used several gearboxes and was able to push half a case of Pepsi. So far, Brian has attended five competitions.

## Sumo Oops!

One day, Brian had just finished putting a new program into a sumo robot. He was carrying it from the programming area in the computer room back to the game table when he dropped it. Down to the floor it went, shattering into many pieces.

Brian thought it was "kind of" funny. Now, that's really taking things in stride, considering he had worked on it for a week. (He and his robotics group did put it back together, though.)

## Programming

Brian's class uses a programming system called the LEGO Robotics Invention System, from LEGO Mindstorms. It uses a variety of pitches to send commands from the computer to the RCX on the robot. The program visualizes how the robot responds to different commands so the kids can see what each command will make the robot do.

## Robotics Builds Passion

Brian wants to help handicapped people someday by building robotics that respond to brain waves and help people with their mobility. *(Maybe he will unveil a groundbreaking robotics design at Tetsujin in the future — Ed.)*

## The "Principal" of the Thing

Sister Roberta Kardell, principal at

Incarnation Academy, agrees that they have a great teaching tool in the robotics program. It is structured to be very interdisciplinary, including both science and math.

The school's latest group robotics project involved simulating the Mars landing. The children completed a research element as part of the project. The robotics program provides opportunities like these to develop skills — skills in finding information and applying it to problems at hand.

## CMU Lends a Helping Robotic Hand

Carnegie-Mellon University's "National Robotics Engineering Consortium" Robotics Academy sponsors several classes, camps, and competitions in robotics which are open to kids in primary education. These are some of the competitions the children were referring to.

This year's schedule includes the FIRST Robotics competition in March, in addition to May Madness (with teacher training sessions at the National Robotics Engineering Consortium).

## Didn't I Tell You?

I told you they were bright, didn't I? They are also team players, problem solvers, and one more thing.

Building bots is a consuming and constructive adventure. High school robotics programs focus all of a

## Resources

LEGO Mindstorms  
<http://mindstorms.lego.com/eng/>

FIRST LEGO League competitions  
[www.firstlegoleague.org](http://www.firstlegoleague.org)

Pacific Northwest  
FIRST Robotics Competition  
[www.usfirst.org/robotics/2004/Agendas/2004PacificNorthwestAgenda.pdf](http://www.usfirst.org/robotics/2004/Agendas/2004PacificNorthwestAgenda.pdf)

East Coast LEGO Freak  
<http://fil-freak.home.comcast.net>  
(Links to information)

The Robotics Institute  
[www.ri.cmu.edu](http://www.ri.cmu.edu)

Robotics Academy  
[www.rec.ri.cmu.edu/education](http://www.rec.ri.cmu.edu/education)

Links to college robotics programs  
[www.cs.buffalo.edu/~hexmoor/robot\\_resources.html](http://www.cs.buffalo.edu/~hexmoor/robot_resources.html)  
(See University Robotics)

child's energies on problem solving — on finding solutions. These kids are already thinking about how they can contribute to society in a positive way.

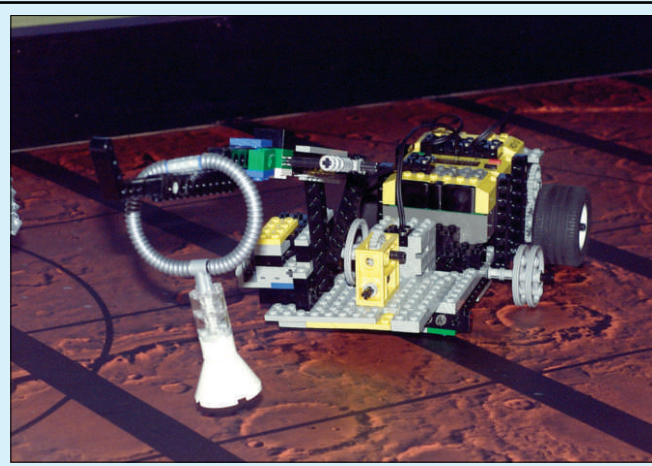
Successful participation in a high school robotics curriculum goes a long way toward bringing us a future full of peace-loving folks who have all of the right tools — both inside and out — that we need to build a better world. **SV**

*Photos courtesy of Jeff Beavers/  
Scott Pipitone Design.*

A team effort.



A handy, object-carrying masterpiece.







# EARLY ROBOTS

BY TOM CARROLL

**P**eople who have been in the robotics field for awhile have seen many machines that are merely large, radio controlled toys and they scoff at calling these machines "robots." Back in 1979, the Robot Institute of America defined the term robot and that definition was accepted at a Tokyo conference on industrial robots in 1981.

*Definition of "robot," according to the Robotics Institute of America (RIA):*  
"a reprogrammable, multi-functional manipulator designed to move material, parts, tools, or specialized

devices through variable programmed motions for the performance of a variety of tasks."

*Definition of "robot," according to Webster:*

"(1) an automatic device that performs functions normally ascribed to humans.  
(2) a machine in the form of a human."

Wow! These definitions might cover those specialized machines that we see in factories, but it doesn't even come close to what a robot experimenter might call her Trinity

College fire fighting robot or what the Sumo robot designer calls his 'bot. There are not too many experimental hobbyist machines that have manipulators, but they most certainly have embedded, programmable microcontrollers.

So, what is a robot? Is it a programmable manipulator arm, performing work in a factory? Is it a differentially driven, two wheeled, mobile platform with a few sensors connected to a microcontroller that allows the platform to navigate its way through a maze? Maybe it's a remotely controlled

teleoperator that a person on the side controls in such a way as to give the illusion that the machine has some sort of intelligence? Hey, if we suck in our personal pride for our own particular preference of a "robot," it's all three — and more.

I'm going to discuss two widely different robots from decades ago. One of the "robots" looked like what most people of that time thought a robot should look like, but it was no more than a teleoperated, promotional robot. The other one was nothing like the way that people of the 1960s-1970s felt a robot should appear, but it utilized two powerful mini computers (powerful for that era) and many sensors. It was much closer to what the purist might call a robot, though it looked nothing like the robots in the movies.

## Electro, The Moto-Man — Servant of the Future

Back in the 1930s, robots as mechanical men were all the rage in pulp science fiction novels and even some movies — a relatively new, increasingly popular form of entertainment. The Great Depression was in full swing and people wanted to look to the future for something better. Westinghouse, a major manufacturer of electrical home appliances, built a huge pavilion on the grounds of the 1939 World's Fair in Flushing Meadows, NY, to showcase its diverse product lines. Its star attraction was Electro, the Moto-Man, and his dog, Sparko.

In keeping with the imagination of the era, let's now depart from the "normal" technical article to envision yourself, first as a young person who loves the robots of the 1930s science fiction and, later, as that same young person, now grown and working as an engineer in 1970.

Close your eyes and take a journey back about 65 years. You are a wide-eyed, 10-year-old kid — straight off the farm — visiting New York City and the 1939 World's Fair with your mom and

dad. You've torn apart a few radios and you even managed to fix your mom's sewing machine a few months ago. Mechanical things are really neat and you want to be an engineer when you grow up.

You follow your parents to the outside of the futuristic Westinghouse Pavilion. Amidst the towering fountains, written above the curved entrance of the pavilion are the words, "The Name That Means Everything in Electricity," referring to Westinghouse. In the front stands a tall cylinder that looks just like a bomb to you. Though you don't realize it, a Westinghouse vice president had once referred to the capsule as a "time bomb" (What was he thinking?), but the president came up with the much more appropriate name of "time capsule." The tall cylinder on display is a mock-up of the real capsule that was buried in the fall of 1938. It contained a lot of microfilm that described the many scientific achievements of the day and was buried 50 feet deep in the ground, not to be opened for 5,000 years.

You follow your parents into the building. Mom is drawn to the displays and demonstrations of the many new kitchen appliances and Dad gazes at a display of Westinghouse railroad car brakes. Bored stiff behind all of the tall people in front of you, you wander about, looking at other displays. In the Hall of Electrical Living, you see displays telling you how electricity has, "lightened housekeeping burdens and made more time for living in the modern home." Who cares, you think to yourself; you want to see the fun stuff.

Suddenly, you see him — a huge, metal man who looks like a silver giant. Your mouth drops open. Wow! It is a robot — just like the ones you see in the books that you check out of the library when you go to town. The robot is smoking a cigarette, just like all the grown-ups you know. He's so tall — seven feet

tall, you later find out. You stand speechless as rings of smoke swirl around his huge head. A pretty lady walks up onto the stage to where the robot is standing, plucks the cigarette from the monster's mouth, and flings it aside.

"Welcome to Westinghouse's Pavilion of the Future," she says, "where the name that means everything in electricity comes alive. This is Electro, the Moto-Man, and beside him is his dog, Sparko. Would any of you like to come up here on the stage beside Electro?" She scans the gathered audience; no one speaks. Suddenly, you see the lady looking straight at you. "Would you like to come up here and say hello to Electro?"

For a second, you are stunned. "Me?" you faintly ask.

"Yes! Come up on the stage and stand by him. He won't hurt you."

You hesitate for a moment and then slowly climb the stairs. Electro is so tall and so shiny and he hums inside and, and .... Your throat is dry as you stand beside him. You are afraid to look up to his face. Suddenly, he moves

A cigarette lighter was an equipment option.





— his arm slowly drops to gently touch your shoulder.

"Hello there," his booming voice echoes through the building. "I am Electro, the Moto-Man, from Westinghouse."

You think to yourself, "Should I run? No, no, he seems okay. You know, he is really nice. Wow, wouldn't it be fun to have Electro with me on the playground? Boy, I'll bet I'd always be the first one chosen in baseball with Electro as my friend. When we play basketball, he would always make a basket."

You wrap your arm around his huge leg — it feels warm, not at all cold, like a bunch of metal. You figure it must be because of all those radio tubes and motors inside of his body. Sparko, Electro's robot dog, stands beside him and then sits at a command from the lady. A camera flash bulb blinds you for a moment as

a newspaper reporter captures your special moment. As your eyes become accustomed to the light again, you see your mom and dad in the back of the crowd, smiling at you. After a bit, the lady ushers you down the stairs and you snake your way back over to your parents.

"Mom! Dad! Did you see me? I was standing by Electro! He's my friend. Dad, can we buy an Electro? He can help me with my homework. He can help me do my chores on the farm. If we can't afford an Electro, maybe we can buy a Sparko. He's a lot smaller and can sleep in my room and I can buy him batteries from my allowance and, and ...."

Your dad smiles at you and says, "Hey, hold it, kiddo. I don't think Westinghouse actually sells robots like Electro or Sparko. They were built to tell people about the real products that Westinghouse makes. If they did sell

Electro, I don't think we could afford it. He'd probably cost \$1,000.00 or more. That's as much as my new tractor."

Your heart sinks a bit, but you snake your way back to the front of the crowd and watch Electro as he does some more movements. You notice that Electro's feet are over two slots in the floor and there are wires leading down under the slots that go somewhere that you can't see. You see wheels on the back of his huge feet that help them slide back and forth on the floor, as if Electro is walking. You realize that there must be someone behind the stage, controlling Electro.

Before your dad takes your hand to lead you away from the display, you pick up a brochure about Electro from the edge of the stage. Inside are several

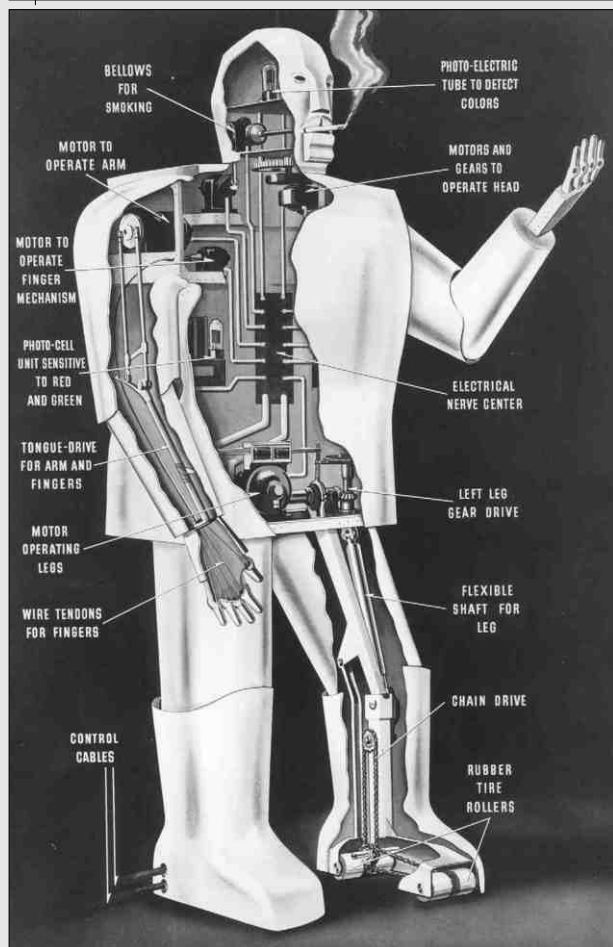
neat pictures of him and his dog, Sparko, plus a history of how Electro came into being. The development of "robots" began at Westinghouse a decade earlier, when "mechano-anthropologist" Joseph Barnett developed the first of the company's talking and walking mechanical men, Televox. This machine was a bit crude, but company officials saw promise in the use of a "robot" as a potential spokesman for the company's products.

The next "robot" to emerge from Westinghouse's robot shop was Willie Vocalite in 1932. This machine could sit up, fire a gun, salute (ah-ha, a potential soldier), and speak in a deep, baritone voice. Willie had a voice coach who taught him to sing some of the songs of the day. For seven years, he represented Westinghouse at various technical functions and conferences, but he was retired to the shop for a complete overhaul. New metal skin was applied and he got a new "nervous" system. Westinghouse knew that the World's Fair was coming up and a new robot would be the ideal spokesperson. Thus, Electro was born.

Electro, at a height of seven feet, towered over mere men. He had more numerous and precise movements than his predecessor, Willie. His chest "expansion" was 82 inches, but, of course, it was always expanded, as it was made of aluminum. His feet were 18 inches long, 9 inches wide, and had cables passing through them to supply power and control signals. His "brain" weighed 60 pounds and was filled with 82 electro-mechanical relays, many signal lights, and two "electric eyes" acting as sensors. All of the motors were connected to gears, chains, and rotating rods that would drive the different parts of his head, legs, arms, hands, and fingers. Electro could even count, distinguish colors, and give a smart, military salute — just like his predecessor, Willie. This seemed like a patriotic thing to do, as war was beginning over in Europe.

As you read a bit further in the brochure, you find out that Electro has a vocabulary of only 77 words and, in the words of the engineer who later spoke to the crowd, "is as smart as the

A peek inside Electro — motors and tubes.



average 10-year-old." Hey, you think, this robot can only speak 77 simple words and only when spoken to. He can't be all that smart — certainly not as smart as me.

Back home on the farm and at your school, Electro and Sparko are all you can think and talk about. You proudly tell your friends about being onstage with the robot and you back it up with a copy of *The New York Times* article that your aunt sent you. It has a picture in it of you standing next to Electro, even though it is in one of the back, "science" section pages. You know in your heart that Electro is not a real robot — a robot with feelings and a machine that can walk around on its own — but, nonetheless, it is one great machine, robot or not.

## The Times, They Are a Changing

You're now 40 and you've taken a different path in life. You received your degree in electrical engineering and work for IBM rather than the "robot factory" that you envisioned when you were a kid and your mind was full of Isaac Asimov's *US Robots and Mechanical Men, Inc.* You've been with the company for 15 years and are now a project engineer in the hard disk drive division.

Thirty years have passed since your encounter with Electro. Yes, there are a few robots in factories — funny, tank turret-like things with manipulator arms sticking out of their fronts — made by a company called Unimation. There are even some robots of newer designs made by other American and Japanese companies, but none are like the ones you read about in Isaac Asimov's many robot stories.

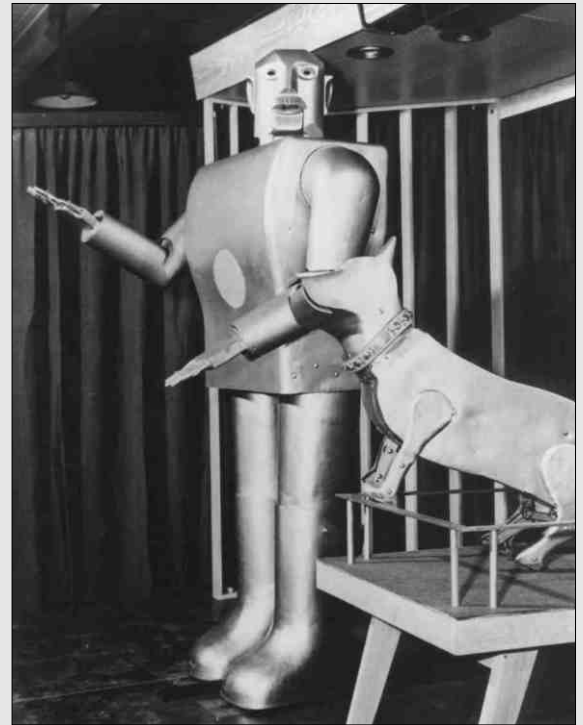
## Shakey — The First Intelligent Robot

On your desk is a photograph of a robot you just saw up at Stanford University. While on a business trip to the Bay Area, you stopped by the university's Artificial Intelligence Laboratory in the famed Stanford Research Institute to see the world's

first intelligent robot, Shakey. World renowned artificial intelligence pioneer, Nils Nilsson, demonstrated Shakey for you and the rest of the gathered crowd of engineers and scientists at a 1970 machine vision and memory conference.

All you could say was, "Wow!" Shakey was as tall as Electro and it was easy to see where it got its name. Balancing on four wheels — two driven and two acting as swivel casters — it wobbled back and forth as it navigated its way around the small, box-filled room. As it approached each box, cameras mounted above the heavy battery and logic box would pan down and optical range finders would determine the distance. The crude video images, range measurements, and positional data from wheel encoders were sent to two computers in a separate room. After a long period of calculations, the new route was fed back to Shakey via the RF link. With the new data on board, Shakey would slowly work its way around the box.

You learned that the robot's arti-



Sparko hears his master's voice.

cial intelligence was composed of four steps of data which the computers had to "crunch." The video cameras, whiskers, and range finders would "sense" the environment. This data was fed into the remote computers, which would "model" the environment. A "plan" was developed



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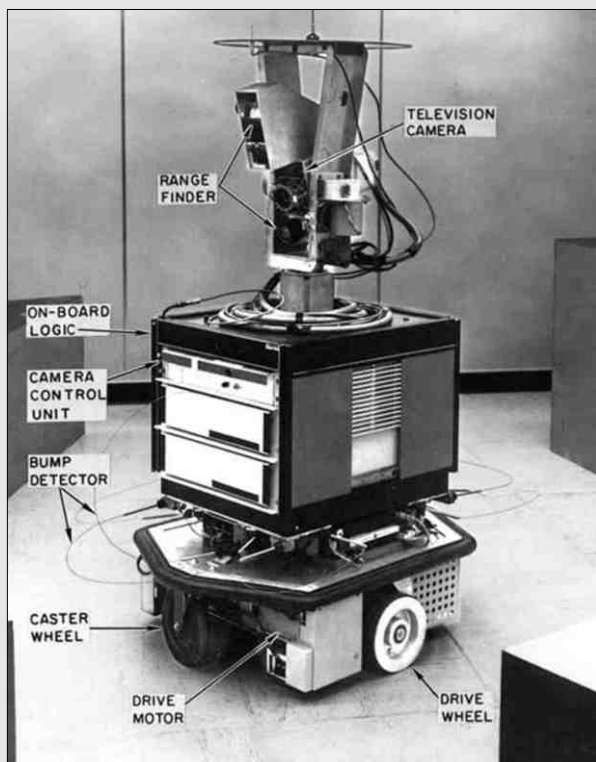
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modern tools for intelligent robotics





Shakey — more advanced than it appears.

and the resulting set of control signals was sent to the robot platform to be “acted” upon.

Nilsson told the attendees, “There will always be some difference between computers and human beings, but I think the intellectual and even creative differences ultimately will narrow.” The boxy, wheeled contraption bumped its way through the room as Instamatic cameras flashed and people watched, dumbfounded.

The television cameras mounted on the robot fed information through RF video and data links to a nearby lab, which housed two DEC mini computers — a PDP-10 and a PDP-15. These computers crunched the data and fed control signals back to Shakey. Whiskers mounted to micro switches served as mechanical feelers. On a very good day and over a period of several hours, Shakey could formulate and execute plans involving moving from place to place and pushing colored blocks around to achieve a goal. The process for Shakey to move one meter could take up to 30 minutes because each small step in a series of movements had to be computed.

Shakey used stored programs for perception, world modeling, and acting upon its environment. Low level action routines took care of simple moving, turning, and route planning. Intermediate level actions strung the low level actions together in ways that accomplished more complex tasks. The highest level programs could make and execute plans to achieve goals given to it by a user. The system also generalized and saved these plans for possible future use.

You lean back in your chair and read over a brochure from SRI which describes Nilsson’s work with Shakey. Nilsson entered Stanford in 1951, just a few years after famed British mathemat-

ician Alan Turing began speculating about the possibility of machine intelligence. Nilsson earned his doctorate in 1958. After three years in the Air Force, he began exploring neural networks as a scientist at Stanford Research Institute. (In 1977, seven years after separating from the university, it changed its name to SRI International.)

Nilsson and his colleagues developed the A\* algorithm in the early 1960s. This algorithm helps search graphs for the shortest distance between two points. (It is used today by anyone who uses mapping applications on the Internet to obtain point-to-point driving directions.) Nilsson determined that neural networks function somewhat like the human brain does. They employ statistical techniques that enable machines to recognize speech and patterns, in addition to performing other useful tasks. Nilsson’s next project at the Stanford Research Institute involved the famous robot named Shakey.

*I hope you enjoyed a bit of insight on these two early robots. These robots seemed so fantastic for their*

*time that they lent themselves well to this fun, fictional manner of writing. Now, allow me to give you some background on early robotic developments.*

Electro certainly wasn’t the first, nor was Shakey the last, amazing robot built by some outstanding people. Some spectacular, purely mechanical, robotic devices were created many decades ago. Even before Shakey made the scene, Dr. W. Grey Walter, a British psychologist, built a unique series of a half dozen tortoise robots in the period from 1948 to 1951. One was named Elsie. These electronic turtles had radio tube “brains,” rotating, photoelectric tube “eyes,” and contact feelers connected to small switches to sense the environment. They were able to detect a light in their nests and go back there when called. What surprised Walter was their social interaction; they responded to each other’s lights when several of them were allowed to roam together.

In 1964, at the Johns Hopkins University Applied Physics Laboratory (APL), researchers built a series of more complex robots; the best known of these later became known as the Hopkins Beast. The Beast wandered the halls of the APL and kept itself in the center of the hall by using side mounted, ultrasonic sonars. When its battery ran low, the Beast used photo cells and a special mask to locate black 120 V wall receptacles on the white walls; it would then plug itself in for “dinner.” One of the Beast versions that I saw many years ago used standard, 7400 series TTL logic hard-wired on circuit boards as its controller, but it worked very well. What would they have given for a PIC or a 68hc11?

I would be remiss to not mention another important robot that was developed in 1965 at Stanford — overlapping part of the period that Shakey was shaking up the place. The Stanford Cart, developed by the Stanford AI Laboratory (SAIL), was originally built to simulate a remote controlled Moon rover vehicle. It was designed by another brilliant robotics and artificial intelligence researcher at Stanford, Hans Moravec. It was actually constructed from a standard

laboratory equipment cart. Between 1967 and 1970, it was completely redesigned to automatically follow a white line on a road. An onboard TV camera transmitted information to a remote computer that controlled the Cart's steering and movement.

Moravec rebuilt the Cart in 1977, when he equipped it with stereo vision. A TV camera mounted on a rail on the top of the Cart took pictures from several different locations as it slid across the rail and relayed them to a computer. The computer then gauged the distance between the Cart and obstacles in its path to maneuver it around these obstacles. The Cart moved in lurches, about one meter every 10 to 15 minutes. After rolling, it stopped, took some pictures, and processed the data for a long time. It then planned a new path, executed it, and paused again, in much the same manner as Shakey did.

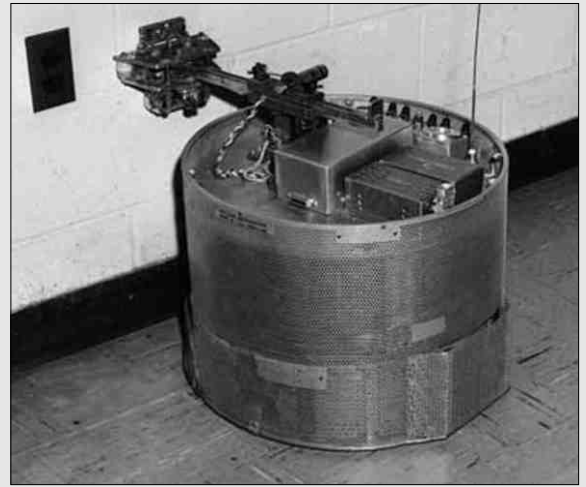
With the Defense Advanced Research Projects Agency (DARPA) and NASA contract funding, Moravec was able to refine the vehicle and its control systems. In 1979, his Cart successfully crossed a room filled with chairs without human intervention. In an outdoor demonstration — with the sun shining — the Cart managed to get thoroughly confused as the sun — with its resulting moving shadows — changed while the computer slowly tried to crunch the data. Moravec's book, *Robot, Mere Machine to Transcendent Mind*, is a must read for anyone in robotics who intends to go past the basic hobby level.

I'd like to finish with SRI's mobile robot, Flakey — the follow-up to Shakey. This robot was a platform about three feet high and two feet in diameter that operated within a closed environment. Two differentially driven wheels provided a maximum speed of about two feet per second. Sensors included a ring of 12 sonar range finders (Polaroid type), encoders on the drive wheels, and a video camera — used in combination with a laser — to provide depth information for a small area in front of the vehicle. Flakey's onboard computers included a workstation and a number of other

processors dedicated to sensor interpretation, motor control, and radio links to outside computers.

Flakey was left to freely roam the SRI offices, coexisting with the staff. It was non-threatening and required no special accommodations by those around it. After a bit, the SRI staff almost ignored Flakey as it roamed around the halls and offices. In a 1992 AAAI mobile robot competition, Flakey was the only entry capable of successfully performing in the object location and mapping event without requiring that the environment be changed to suit its particular needs. One judge felt so at ease with Flakey's onboard intelligence that he said, "Flakey is the only robot I felt I could sit or lie down in front of."

I have highlighted two robots in this article, but I wanted to show that researchers and experimenters are never satisfied with a particular design. Westinghouse and SRI are only two of the many companies and schools which have been continually striving to improve their designs with exceptional machines. **SV**



✚ The Hopkins Beast, about to recharge itself.

### A SPECIAL THANKS ✚

I am indebted to Charlie Rucks, now retired from Westinghouse, for the photographs of Electro. Back in 1983, he spent many hours helping me locate the photos for a book, *The Robot Revolution*, which I was helping Tom Logsdon write. Charlie worked in Westinghouse's archives at their headquarters in Pittsburgh, PA.

I also took a bit of fictional license in describing Sparko, Electro's robot pet dog, at the 1939 Fair. He actually did not appear until 1940.

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## The Low Down on the Low Level:

# STATE MACHINES

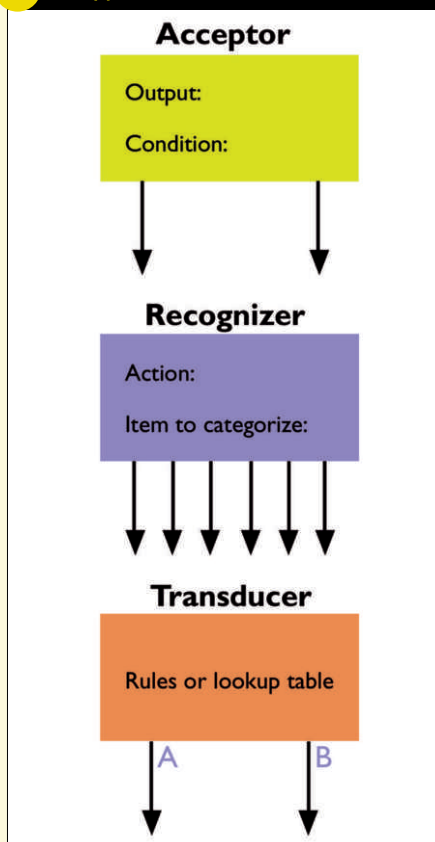


by Jack Buffington

## What Is a State Machine?

If you have been involved with programming and robotics for very long, it is likely that you have come across the

### 1 Types of state machines.



term "state machine." State machines are hardware or software that have a predetermined structure and sequence of operations. A state machine has one or more states, which are essentially places that the software or hardware stays until some external stimulus causes the execution to move to another state. In general, each state has at least one link to another state and a set of conditions that must be met before its execution can move elsewhere. State machines are often explained using cryptic notations and hard-to-follow diagrams. This article will attempt to explain them in plain English, so that they are easier to understand.

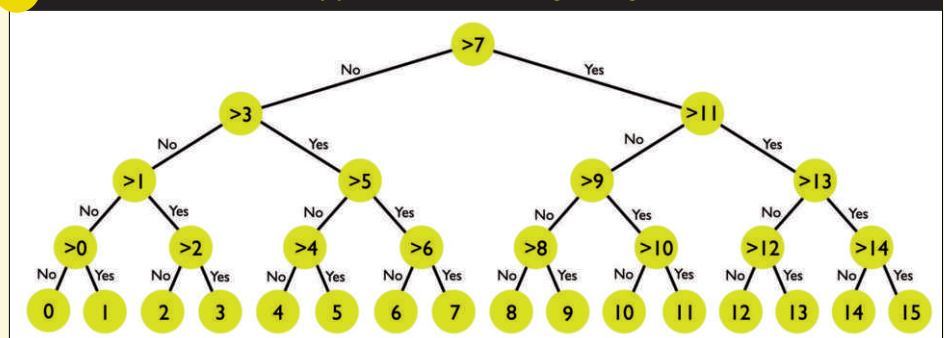
## How Are State Machines Organized?

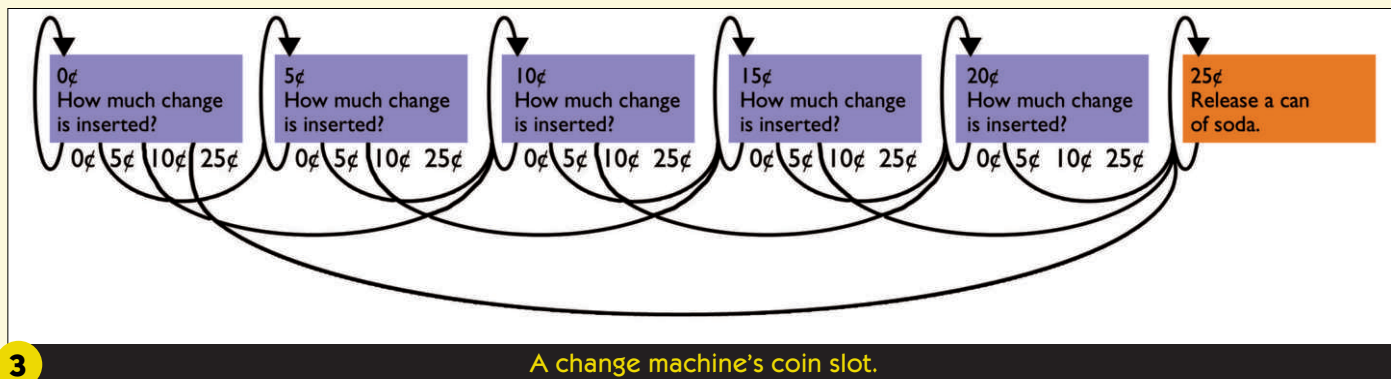
State machines have at least two

states they are able to be in. A one-state state machine would never change its operation; it would do the same thing forever. When you have more than one state, you can start to create more complex results from your input. A good way of visualizing how a state machine works is to create a map of how the states are arranged.

An example of a state machine can be seen in many analog to digital converters, which use a process called successive approximation to figure out what voltage is coming into them. Essentially, this process passes the initial value to a series of states. Each state decides if the voltage input is or is not greater than a certain value. By progressively testing for smaller and smaller voltage ranges, the analog to digital converter can find the proper

### 2 A successive approximation analog to digital converter.





value to give as its answer. Figure 2 shows how a four-bit analog to digital converter might work.

The previous example consisted of states called acceptors. Acceptors take input and either accept it or reject it. If they accept their input, program execution will be sent down one branch; otherwise, execution will be sent to its other branch.

Recognizers can be thought of as another kind of state machine; however, they are not actually true states because any recognizer can be broken down into two or more acceptors. Still, it helps to think of a recognizer as a true type of state machine because it simplifies the task of designing a state machine. Recognizers do not output any data, but categorize input into three or more outcomes. The result of this categorization will determine which program branch to take.

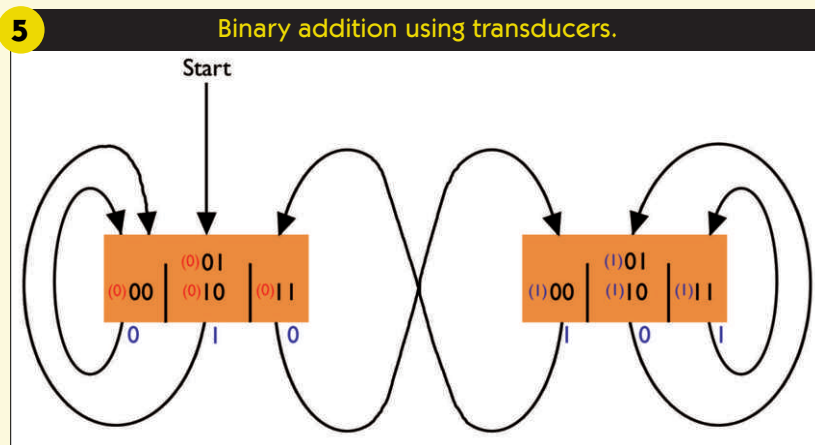
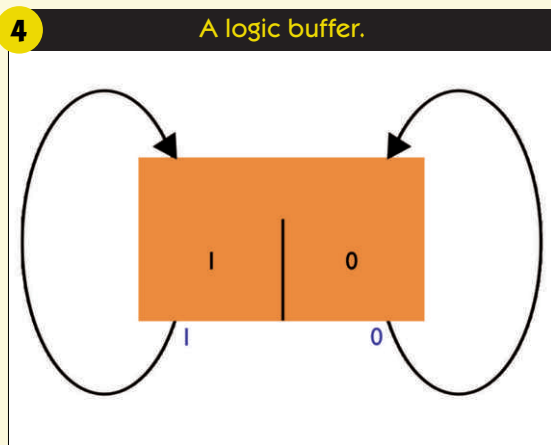
A soda machine coin slot

mechanism represents the classic example of a recognizer. In deciding if enough change has been put in, the decision making is done entirely by recognizers. To keep Figure 3 simple, alterations in state that resulted in excess change being inserted were not drawn.

The third type of state machine is known as a transducer (Figure 4). Transducers take input and not only direct execution to other states, but also produce an output. Transducers can direct execution to one or more different states. They do not need to produce an output for every piece of data that they input; instead, they manipulate data, enabling their use for more complex tasks, like math or logical operations.

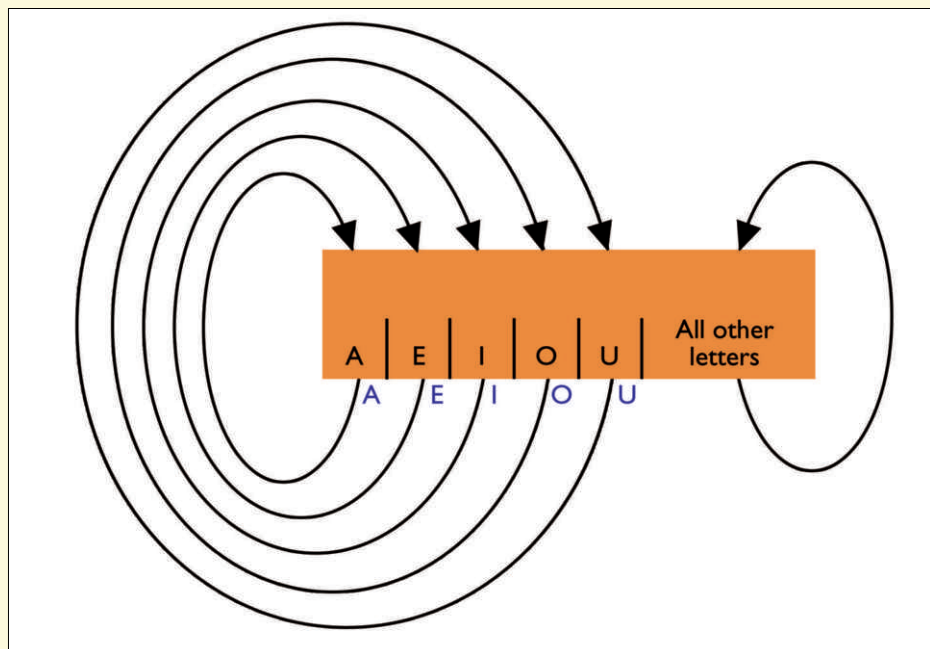
Figure 5 is a simple transducer. It simply outputs the same data that is given to it. The transducer looks at the data that is input and, if it is a 1, then

it matches that with the left branch of execution. The 1 next to the left arrow shows that, when execution occurs at that location, the transducer outputs a 1. If it takes the right branch, then it will output a 0. Figure 5 is a simple transducer that performs binary addition. It contains two operational portions: one on the left to handle adding two binary digits in the absence of a "carry" bit, and one on the right to handle the two digits with a "1" carry. Execution begins on the left portion but switches to the right when sum generates a carry bit (the case of adding two ones). It then stays on the right until no further carry bits are generated, at which time it moves back toward the left. You can think of the right portion as actually adding up three binary digits, one of them always a "1". (The left portion also adds three digits, but since one is a "0" you can simply ignore it.) Here are some





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**6** A state machine that only outputs vowels.

sequential examples that you can trace through to see if you understand the operation.

(Start on left side)

$1 + 0 = 1$  — and stay on left side

$1 + 1 = 0$  — and move to the right side, carrying a 1

$1 + 0 = 0$  — actually  $1 + 0 + 1$  (carry

bit), so emit a zero and stay on right side

$1 + 1 = 1$  — including the carry keeps execution on the right portion

$0 + 0 = 1$  — finally getting rid of that carry bit, move back to left side

The real power of transducers is in their ability to do more sophisticated

processes. Here is an example of a state machine that can do addition. Let's work through an addition problem and see how this state machine works.

```

110010110
+100110011
1011001001
    
```

For each time we arrive at a transducer, we input two bits. These bits are from the two numbers to be added, starting with the bits on the right and moving to the left. The first pair of bits will be 01, which represents the far right bit from each number to be added. The transducer will output a 1 and cause execution to stay at the transducer on the left. The next pair is 11. In binary math, this results in a 0; the transducer outputs this answer and moves execution over to the transducer to its left. The third pair is 10. The transducer outputs a 0 and passes execution to the next transducer. This process continues until the last pair of bits, which sends the state machine over to the transducer on the right. The transducer has now finished adding all of the digits together, but the answer is not correct yet. To get the proper

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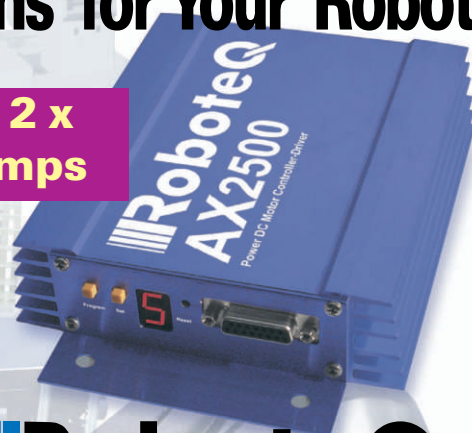
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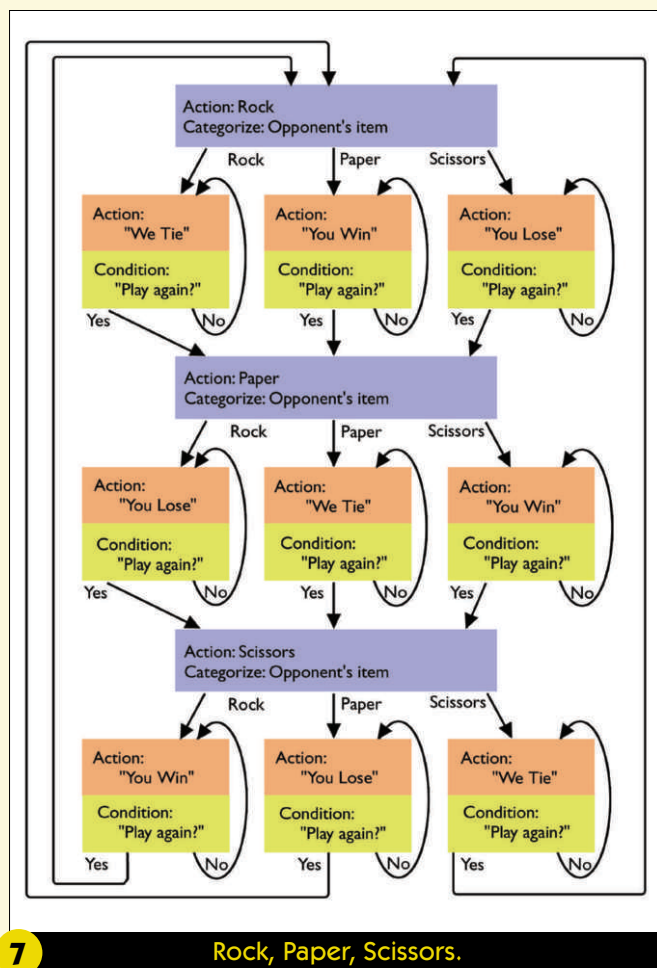
answer, it needs to add a 0 to the left of each binary number. Running the two 0s through the transducer on the right completes the addition and gives us a 1 for the most significant bit of the answer.

Transducers don't just have to deal with binary numbers. They can be made to do things like reversing the letters of the alphabet as a simple sort of encryption or figuring out the parity for serial transmissions. Figure 6 shows one that outputs only the vowels that are input into it.

A state machine that used all three types of states would be represented by one that could play the game Rock, Paper, Scissors (Figure 7). This machine would have three categorizers to take the opponent's selection and direct execution to one of three transducer states, which would indicate a win, loss, or tie before

passing execution to an acceptor state that waits for the player to choose to play again.

Hopefully, this article has helped you understand what a state machine is and what it can do. Although state machines are not easily applied to higher-level concepts — such as robotics — there are times when structuring a part of a program that you are writing to replicate a state machine can make your programming task easier. **SV**



## Author Bio

When not writing for *SERVO Magazine*, Jack runs Buffington Effects, a company that designs and builds animatronics and motion control devices for the entertainment industry. Check out his website at [www.BuffingtonFX.com](http://www.BuffingtonFX.com)

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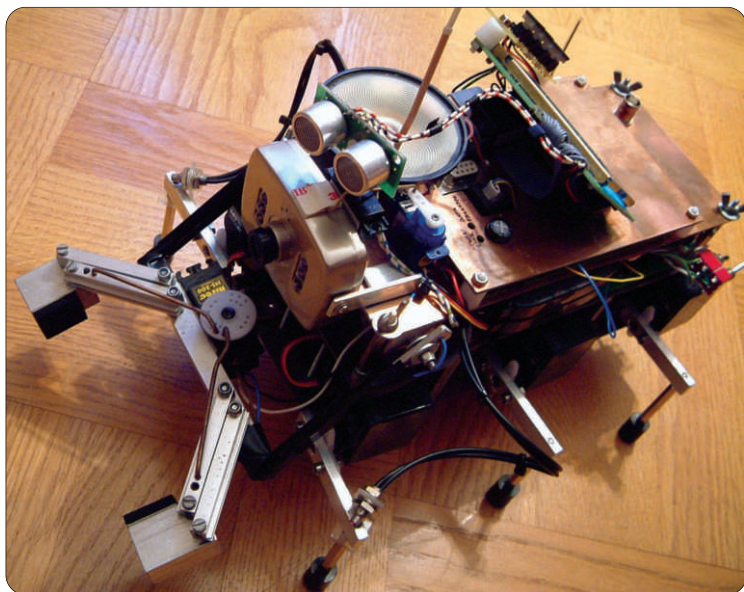
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Tobias Reneskog, Sweden

HexaTron is a six-legged robot, built to traverse rough terrain. Its chassis is made of an unetched circuit board and each leg has two degrees of freedom.

Its brain is an Atmel AT89S8252 microcontroller with 32 KB of battery-backed RAM, which contains both the program and variables. The leg servos are controlled by an SD20 servocontroller chip, via an I<sup>2</sup>C bus.

It has two fiberoptic photocells connected to the front legs for obstacle detection. Others are detected via an SRF04 ultrasonic rangefinder, which can rotate 180°.

It is controlled via a duplex radio link and it also has an onboard color camera and wireless video link. I usually control it via a homemade program, which shows camera feeds, status messages, and a radar-like graph of its surroundings as seen by the ultrasonic rangefinder.

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# The INVASION of the CENTIBOTS!

by Edward Driscoll, Jr.

**R**emember the robot mouse in *Star Wars*? Chewbacca turns a corner in the Death Star, sees one of these little, box-shaped robots, looks down, and lets loose a bellowing roar. The robot's little wheels send it reeling off in fear.

The mouse robots were apparently on the Death Star to map it, so that soldiers and technicians could find their way through its maze of corridors and control rooms.

Now, imagine yourself walking through a modern, multistory office building on a 63-acre lot in Menlo Park, CA — in Silicon Valley's haven of high tech and venture capitalists — seeing 100 equivalent little robots rolling past your feet, up and down through the corridors.

That's what it felt like when I toured the facilities of SRI International this past December. SRI has been around since 1946, when it was known as the Stanford Research Institute. Among their innovations, SRI helped invent detergent when, in the 1940s, their research discovered the cleaning potential of dodecyl benzene, a petrochemical substitute for coconut oil. In the 1960s, they were one of the first four nodes of the Arpanet, the beginning of what would eventually be known as the Internet. Douglas Engelbart, who created the computer mouse in the mid-1960s, was an SRI employee.

Also in the 1960s, SRI developed

"Shakey," a robot created in their pioneering artificial intelligence center. Shakey was a mobile robot with the ability to reason about its surroundings through sophisticated perception and location capabilities. (*To learn more about Shakey, read Tom Carroll's article, "Early Robots," in this issue.*)

## Robots Acting as a Team

In the past, robots such as Shakey have been independently built and operated. With the possible exception of factory assembly line robots, most robotic experiments involved designing single robots that acted more or less





■ ■ ■ SRI's Dr. Regis Vincent poses with a few of his Centibots.

autonomously.

But Centibots ([www.ai.sri.com/centibots/index.html](http://www.ai.sri.com/centibots/index.html)) are different — they act as a team — and SRI is part of a team, as well, working with Stanford, the University of Washington, and ActivMedia Robotics.

The project was funded by DARPA — Defense Advanced Research Projects Agency ([www.darpa.mil](http://www.darpa.mil)) — the central research and development organization for the Department of Defense. DARPA's goal for the Centibots was to create a team of up to 100 robots for

such missions as urban surveillance, mapping of building interiors, and search and rescue. The military's term for what the robots are designed to accomplish is "force multiplier"; the idea is that one soldier can manipulate and control hundreds of the robots, which are sent into a building or a perimeter. Needless to say, if there's a booby trap or a mine, it is far better that a robot triggers it instead of a soldier.

SRI describes a typical Centibots mission: First, a team of three or four mapping robots (built on ActivMedia's

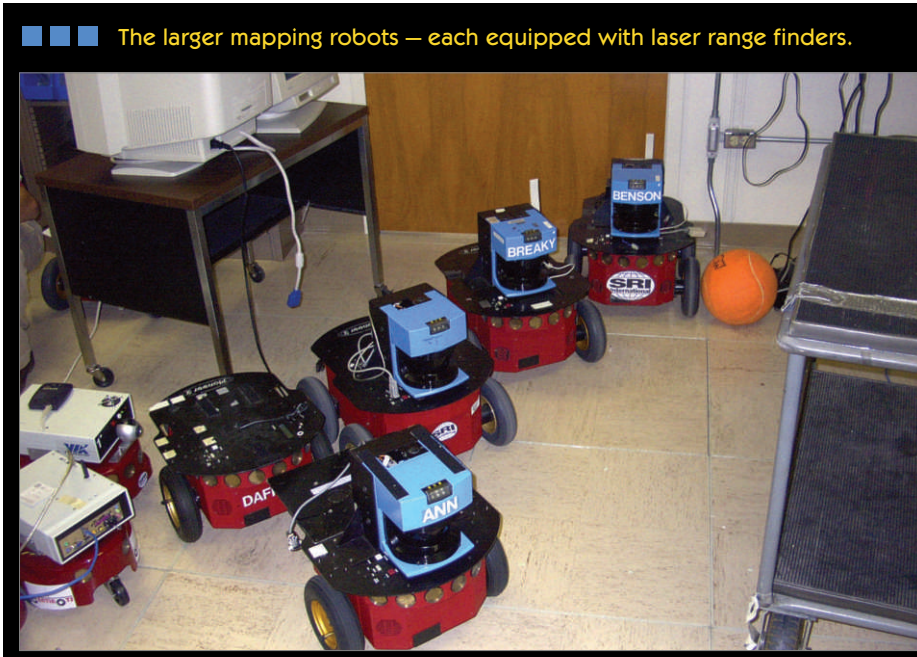
larger Pioneer-3AX and DX chassis and equipped with laser range finders) surveys an area, while building and sharing a distributed map. They're followed by a second wave of tracking robots (which use ActivMedia's much smaller "AmigoBot" chassis) that configure themselves to efficiently search for an object of interest within that area, sense and track intruders, and share information among themselves and with a command center.

The robots are autonomous and independent of any network infrastructure, carrying and deploying their own communication network (using SRI's PacketHop technology over 802.11 wireless frequencies). The Centibots communicate with each other to coordinate their effort. If one robot fails, another takes over its task. The larger, mapping robots have a three-hour battery life; the smaller, AmigoBot-based robots have five hours of battery life. When a robot is wearing out, a replacement robot automatically rolls in to take its place. If the programming in one of the Centibots fails, it's designed to automatically return home as best as it can.

The goal of the Centibots project is to advance the state of the art in distributed robotics. Their development is structured to exploit existing research solutions that are fairly well-developed and robust (self-localization, path planning) and then to identify and explore areas where research is still needed, but solutions are being created (real-time map construction, multi-robot concurrent mapping), as well as areas where significant research is needed (human and robot interaction, team formation).

On the theoretical side, SRI says the research areas that the Centibots project is expected to advance include creating a multi-level architecture that is not only adaptive to new tasks and team organization, but also scalable to very large teams. They also provide testing for SRI's PacketHop technology — a large-scale, fault-tolerant communication network. SRI also hopes the Centibots will advance robotic team interface designs, including monitoring and robotic interaction with humans.

Centibots have practical



■ ■ ■ The larger mapping robots — each equipped with laser range finders.



applications, as well. The maps created from the data the Centibots collect are extremely detailed, down to showing if a building's interior doors are open, partially open, or closed. Once a team of robots can be sent into an unknown building, build a map in real time, and deploy themselves to search the building, practical applications abound. The robots could be sent into areas that are not safe for humans (collapsed or earthquake-damaged buildings, chemical spill sites, burning buildings, terrorist-occupied structures) or areas where humans could not see anything (smoke-filled buildings), but robot sensors can. Wherever they may be deployed, the robots could build maps and search for people in need of rescue.

## Building and Programming the Centibots

Needless to say, the programming of the Centibots is extremely sophisticated, but, almost paradoxically, most of the hardware they use is strictly off-the-shelf and much of it can be picked up at the Silicon Valley Fry's Electronics store. (On the other hand, I think most of the parts that make up the *USS Enterprise's* warp drive can be purchased at Fry's.) As we said, the chassis of both the larger and smaller robots were created by ActivMedia ([www.activmedia.com](http://www.activmedia.com)). The 802.11 cards the robots use are by Netgear. The cameras which comprise the robots' eyes are by Logitech.

The goal is to keep the cost of each Centibot under \$5,000.00 and to make field repairs as easy as possible. (The larger robots, built on the ActivMedia Pioneer chassis, cost several times more though — about \$20,000.00 each.) Incidentally, SRI has a pretty thorough webpage on the parts that went into the Centibots ([www.ai.sri.com/centibots/tech\\_design/index.html](http://www.ai.sri.com/centibots/tech_design/index.html)).

## Centibots Go to Work

In January of this year, the Centibots and their SRI human masters

were sent to DARPA's installation at Fort A. P. Hill in Virginia ([www.aphill.army.mil](http://www.aphill.army.mil)). Dr. Regis Vincent of SRI says, "We were given an area of about 688 square meters. We had not rehearsed in that environment — it was completely unknown — and DARPA asked us to set up our system and run through a series of tests. Every room was instrumented with cameras, so that they could actually track any robots coming into any rooms and see if the robot was performing as they wanted."

Vincent describes the building as containing about 16 rooms, "a mix of big, empty rooms, and small, tight corners. It was an old schoolhouse that had been remodeled several times since the 1900s. So, you had a big, open area and small areas that used to be crowded and passageways to a new wing extension. So, it was actually a very interesting building."

The first task of the Centibots was to assemble a map of the building. "We did several tests with first one, then two, and then three robots to map the building. It took us about 20



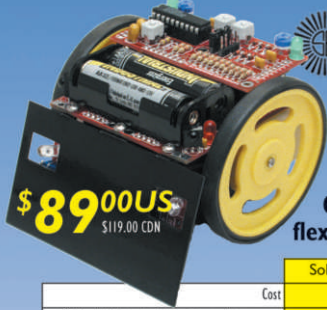
Centibots on patrol in SRI's Menlo Park, CA offices.

minutes for one robot to map the building."

The Centibots managed to map 98 percent of the building. "When it was complete," Vincent says, "DARPA's evaluation people decided that they should go back and make a better map because our map was way better than what they had."

## The Centibots' Long and Short Term Future

So, what happens next to the



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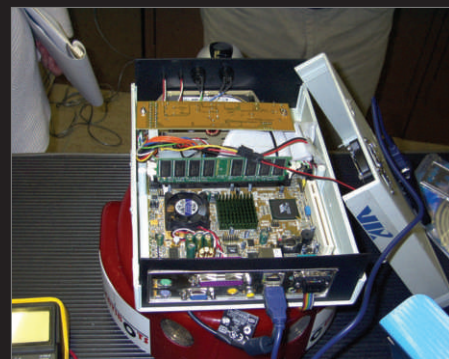
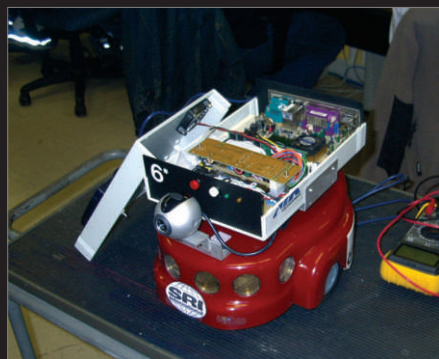
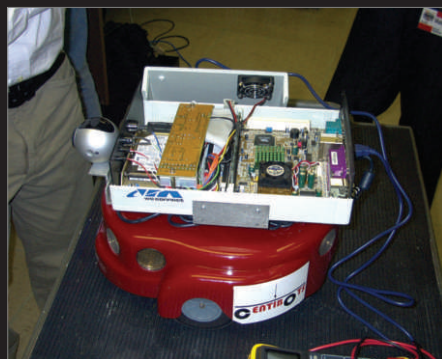
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Under the hood of a typical Centibot. Many of the parts can be bought in a well-equipped computer store.

SRI's Mission Control for the Centibots, where off-duty 'bots relax between mapping assignments.



Centibots? Long-term, Vincent says it's, "a good 10 years," before they'll be deployed in the field. "You have to think about designing 'rugged-ized' robots that can last for more than one or two hours. You might have fuel cell based robots, where you put hydrogen or gasoline in and the robot will run for an extended period of time and, also, more research and working with the military to integrate their search teams with the robots is necessary."

Another problem with the Centibots is that they currently need a team of technically advanced people to run the system. It's not yet a turnkey system where one or two soldiers in the field can deploy them if they find, for example, a hostile building or cave that needs exploring. The user interface needs to be simplified, Vincent says.

## Short-term? eBay!

Vincent says, "We'll keep a handful of them; I think we're going to donate a couple of them to local high schools for robotics competitions, but the bulk of them will likely end up on eBay." Vincent says the starting bid will be, "in the low \$400.00 or \$500.00 range, something like that. That's for the small robots. The bigger ones, we'll keep those. We can reuse them on different projects."

So, while the Centibots won't be deployed in the Middle East anytime soon, they could be on patrol at your house. Warn Chewbacca, if he stops by for dinner. **SV**

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Micro-Bot is a wheeled robot controlled by a PIC MCU. Includes a free demo version of the PicBasic Pro Compiler, as well as sample programs, parts kit for infrared & photocell experiments, schematics, and projects for RF remote control & sonar range-finding/navigation.

Phone: (719) 520-5323 Fax: (719) 520-1867 Box 60039, Colorado Springs, CO 80960

# New Products

## ACCESSORIES / PARTS / COMPONENTS

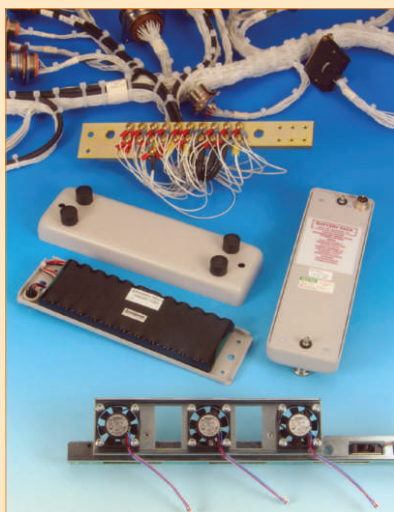
### Packaged Small Box Assemblies Combine Components, Enclosures, and Cabling

A new, value-added service that simplifies engineering, purchasing, and assembly by combining multiple components into one package — with one part number — is being introduced by Aved Electronics of Lowell, MA.

Aved Small Box Assemblies combine a variety of components into one fully integrated package to improve efficiency, reduce parts counts, and simplify operations. Featuring custom battery packs, motors, fan trays, panels, meters, enclosures, cables, and connectors, these small box assemblies are 100% electrically and mechanically tested and can be UL/CSA approved.

Specializing in designing external battery packs that look and feel like the host product or instrument, Aved Small Box Assemblies can be engineered to solve specific space and functionality problems. Battery chemistries can include Li-Ion, NiCad, NiMH, and others and cable assemblies can be built to meet rigid industrial and MIL Specifications. Aved Small Box Assemblies are priced according to configuration and quantity. Literature and price quotations are available upon request.

For further information, please contact:



**Aved Electronics, Inc.**

59 Technology Dr.  
Lowell, MA 01851  
Tel: 800 • 441 • 2833 Fax: 978 • 453 • 6470  
Email: [info@aved.com](mailto:info@aved.com)  
Website: [www.aved.com](http://www.aved.com)

Circle #117 on the Reader Service Card.

### MEMS Accelerometers & Rate Gyros

O-Navi now has available two new low-cost MEMS inertial sensors for measuring angular rate or acceleration in applications such as robotics and vehicles. The

new sensor modules are the GyroPAK single axis rate gyro and the XL-PAK dual axis accelerometer modules.

The GyroPAK is a single axis MEMS angular rate sensor available in  $\pm 200^\circ/\text{s}$  and  $\pm 400^\circ/\text{s}$  sensitivities. Custom scaling is available from  $\pm 45^\circ/\text{s}$ . A standard analog temperature output is provided for off board compensation, if desired.

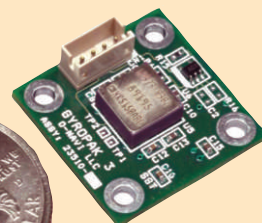
The XL-PAK features a dual-axis solid state MEMS accelerometer sensor available in  $\pm 2g$  and  $\pm 10g$  sensitivities. Custom scaling is available from  $\pm 0.5g$ . An optional temperature output is also available.

Both sensor modules feature reliable solid state MEMS technology in a compact 20mm square module and are mountable in nearly any orientation. Both modules have an easy to use 0-5V analog interface and require a single 5 volt DC power source. Optional evaluation kits are available with all cables and power supply to quickly power up and test the modules.

O-Navi's MEMS inertial sensors are very compact with low power consumption, making them particularly useful in battery powered applications such as closed loop control for steering, stabilization, balancing robots and vehicles.

O-Navi offers an extensive line of rate gyros, accelerometers, magnetometers, 3-axis IMUs and GPS navigation and tracking systems for robotics, autonomous vehicles, avionics, and automotive applications.

For further information, please contact:



**O-Navi, LLC**

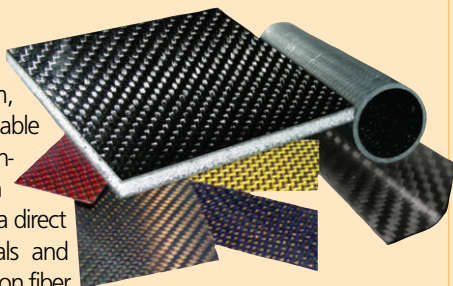
2430 Vineyard, Ste. 201  
Escondido, CA 92029  
Tel: 760 • 672 • 7788 Fax: 760 • 874 • 2850  
Email: [info@o-navi.com](mailto:info@o-navi.com)  
Website: [www.o-navi.com](http://www.o-navi.com)

Circle #140 on the Reader Service Card.



### Carbon Fiber Composite Products

Carbon fiber, Kevlar, Texalium, hybrids are now available for your personal high-tech projects. They can be molded or used as a direct replacement for metals and plastic. Benefits of carbon fiber include:



- Very high strength to weight ratio.
- High resistance to fatigue.
- Harmonic dampening characteristics.
- Impact resistance.
- Low coefficient of thermal expansion.
- Resistance to corrosion.

The Robot MarketPlace is able to provide retail and business customers with the highest quality carbon fiber products, including carbon fiber angle, braided and seamless carbon fiber tubing, and the incredibly rigid carbon/foam sandwich panels, with very high strength and low weight, obtaining similar structural qualities as an "I" beam.

They are also able to offer raw fabric and finished sheets layered with Hexcel Texalium for cosmetic appeal. This material is coated of 99% pure aluminum. Potential applications of advanced carbon fiber composites are endless.

For further information, please contact:

**The Robot Marketplace**

Website: [www.robotmarketplace.com](http://www.robotmarketplace.com)

Circle #124 on the Reader Service Card.

### New Speech and Music Synthesizer IC

Speechchips.com has added the Magnevation SpeakJet to its line of speech synthesizer components. The SpeakJet generates 72 speech allophones, 43 sound effects, and 12 DTMF Touch Tones. Through the selection of these sounds and by controlling the pitch, rate, bend, and volume parameters, users have the ability to produce unlimited phrases and sound effects. The SpeakJet can be controlled simultaneously by logic changes on any one of its eight Event Input lines and/or by a single I/O line from any CPU, such



as a PC, OOPic, or BASIC Stamp. This allows for both CPU controlled and stand alone operations.

For further information, please contact:

**speechchips.com**

35 Middle St.  
Westbrook, ME 04092  
Fax: 928-569-4997  
Email: [ken@speechchips.com](mailto:ken@speechchips.com)  
Website: [www.speechchips.com](http://www.speechchips.com)

Circle #132 on the Reader Service Card.

## COMMUNICATIONS

### Lower Cost Alternative to National Instruments' PCI-6070E Offers Identical Specifications

Measurement Computing Corporation announced the release of the PCI-DAS6070 board. The PCI-DAS6070's \$1,050.00 price makes it an attractive alternative to the NI PCI-6070E, which sells for \$1,495.00. The PCI-DAS6070 offers specifications identical to the NI board and costs \$445.00 (30%) less.



The PCI-DAS6070 provides 16 single-ended/8 differential channels of 12-bit (one part in 4,096) analog input. Measurements on any of 15 input ranges may be taken at rates up to 1.25 ms per second. The board offers dual 12-bit analog outputs with 1 MS/s per channel maximum update rates. Eight digital, bi-directional I/O lines can control relays and solenoids, in addition to monitoring switch and contact closures. The board also provides two 16-bit counter/timers.

The board is fully supported by LabVIEW™, SoftWIRE®, Agilent VEE™, LABTECH®, and MATLAB®. Users wishing to program in Visual Basic, C#, C++, or any other popular language can use Measurement Computing's powerful Universal Library (UL). UL speeds the programming task with high-level, easy-to-use functions, with access to all of the board's functionality and low-level functions.

The PCI-DAS6070 is one of many lower priced alternatives to National Instruments' E-series/PCI-6000 boards. All of these boards offer the same specifications as their NI counterparts and are offered at 25-30% lower prices.

For further information, please contact:

**Measurement Computing**

16 Commerce Blvd.  
Middleboro, MA 02346  
Tel: 508-946-5100 Fax: 508-946-9500  
Website: [www.measurementcomputing.com](http://www.measurementcomputing.com)

Circle #151 on the Reader Service Card.

# ROBOTS ROBOTS ROBOTS

by Dave Calkins

The International Robot Exhibition (IRE) is an annual show in Tokyo, Japan, showcasing the newest and coolest in robotics. It's held in one of the coolest buildings in the world — the Tokyo Big Box. Imagine four upside-down pyramids and you will get the idea (Photo 1).

The most common robot today is, of course, the industrial robot: robots that load pallets (Photo 2), move whole vehicles (Photo 3), paint car bodies, and much more (Photo 4).

Security is a huge concern in this day and age and companies are trying to meet the demand. Fantastic robots were on hand — such as Subaru's mine clearing robot and Alsok's Security and Information Robot — both of which can help you find out how to get where you're going, in addition to acting as security guards (Photo 5).

Of course, if you really want to be secure, what could be better than your

own robot dinosaur (Photo 6)? Banryu's NeoDinosaur (T73S) has 360 degree vision, multiple cameras, and enough power to let your kids ride on it. It even barks and wags its tail when it's happy. Of course, I didn't know that dinosaurs barked, but then again, I didn't realize that they were orange, either ...

*The robots that most people like are the ones that both interact and look like humans — the IRE had them in spades.*

- Need a brochure? Brochure-bot (Photo 7) is a happy little robot that hands them out as you pass by.

- After a long, hard day of hanging out at a convention, you need a break. Of course, entertainment is part of lunch — so what could be better than singing, dancing robots that crack jokes and make fun of customers' ties (Photo 8)?

*Thousands  
of 'em ...*

- Industrial Robots
- Toy Robots
- Competition Robots
- Snake Robots
- Robotic Exoskeletons
- Robot Hands
- Dancing Robots
- Cute Robots
- Ugly Robots
- Translation Robots
- Entertainment Robots
- Security Robots

**ROBOTS!**



Photo 1



# Robots, Robots, Robots ▶▶▶▶

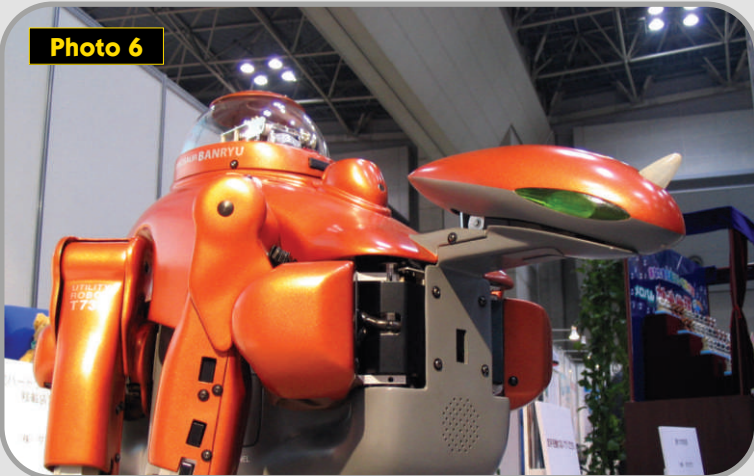
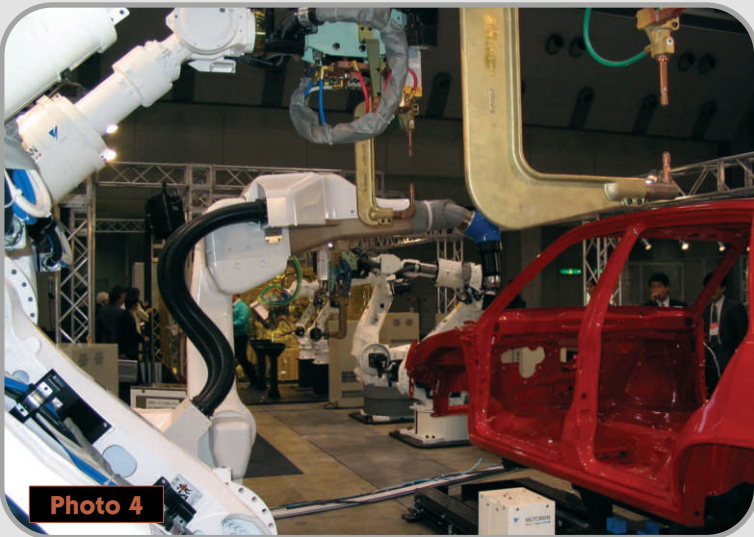






Photo 7



Photo 8



Photo 9

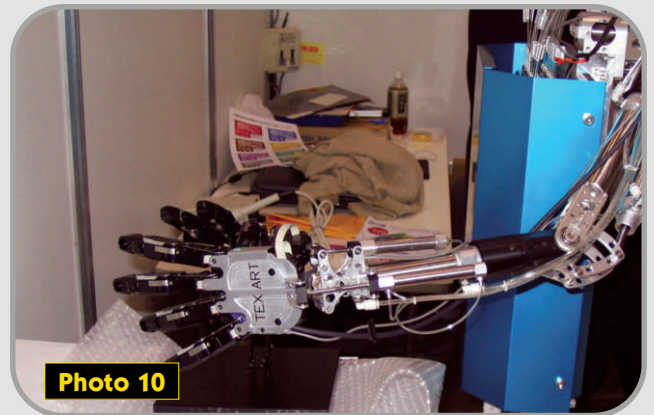


Photo 10

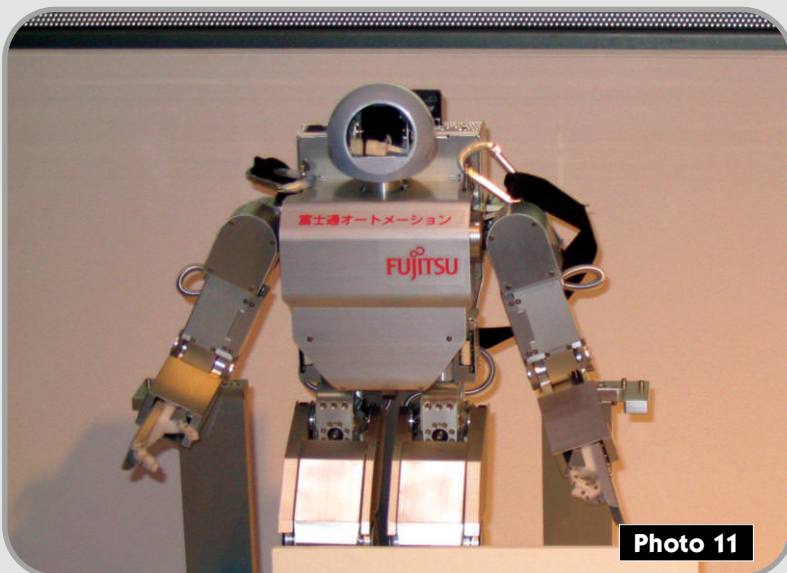


Photo 11

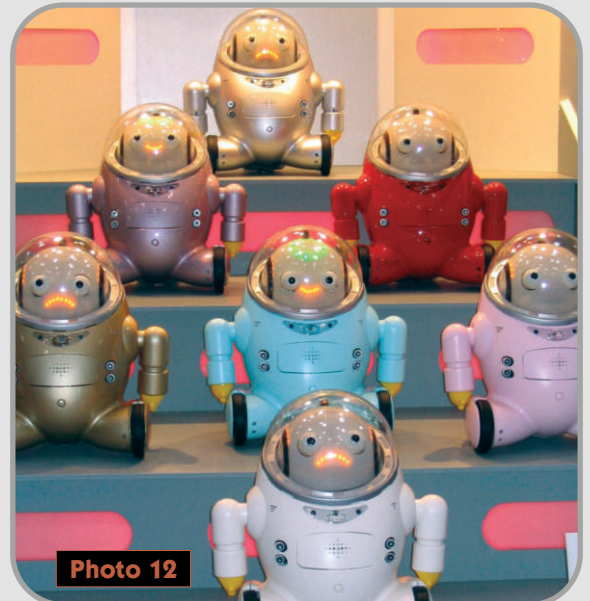


Photo 12





Photo 13

• Epson's famous EMROS dancing robots are no bigger than a quarter. These little guys use Bluetooth to communicate with each other and perform coordinated dances (Photo 9).

• Wouldn't you give a hand to a friend (Photo 10)?

• Fujitsu's new HOAP is as articulated as the most agile Kung Fu master, but costs a bit more — \$75,000.00 (Photo 11).

• They're small, they're cute, and — ostensibly — they translate (Photo 12). I sure could have used a working one, since not everyone spoke English, but neither did the bot — which was its marketed purpose. Oh, well. They're cute!

• Anthropomorphic robots weren't the only machines on hand that looked like humans. The Cybernetics Lab of the University of Tsukuba was demonstrating their bionic legs (Photo 13). These external legs work on nerve impulses to raise its wearer's legs and support a body which is unable to move on its own. Iron Man, eat your heart out.

• Kawada's Promet was the hit of the show (Photo 14). While there are many 15-inch tall androids being released, Promet is the first full-sized robot that can walk, lift, carry, sit down, lay down, and perform just about all the other motor functions that you and I take for granted. While it's not as fast

as your average five-year-old (then again, I'm not as fast as your average five-year-old), it can lift a table and carry it across the room with deft agility. Kawada doesn't expect to be selling Promet in the near future — much like Honda's Asimo is only an ambassador for Honda and won't be available for retail. Still, it's as much a glimpse into the future of robotics as Apple 2s were a glimpse into the future of the PC.

*Imagine if you will: What would happen if you crossed BattleBots®, Honda's Asimo, Sumo Robots, and good, old-fashioned Rock 'Em Sock 'Em Robots? Close your eyes and think about it. If you're the impatient type and want to see the future right now — look ahead at the next page.*

## The Coolest Thing Ever

It's called Robo-One. If you thought that the Sony Curio (formerly SDR) and Fujitsu HOAP were cool — well, you were right — but either one will set you back as much as a fully loaded BMW. A Robo-One? It only costs about \$3,000.00, but these little guys aren't wind-up dolls.

Robo-One is it. It's what we've all been waiting for all these years: inexpensive androids that have as much range of motion as a human. (Alright, 15-inch tall androids, but what do you expect for \$3,000.00 — your own personal Anthony Daniels?) These guys can roll over, climb stairs, tumble, side kick, wrestle, and much, much more ...

With onboard (and, occasionally, off-board) computing, they know which way is up and have many moves programmed into them (much like you — in a singles' bar). The operator tells the robot which way to go and which action to take, but doesn't have to worry about which foot goes first or

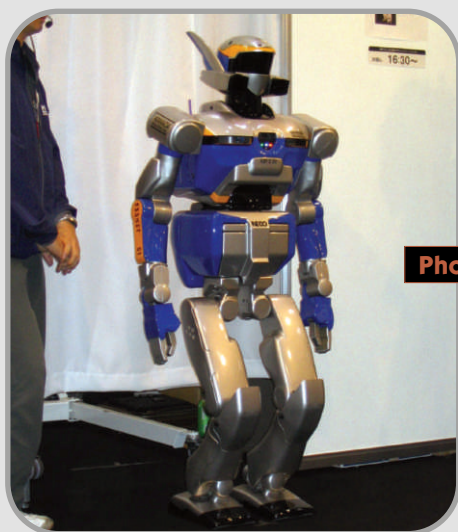
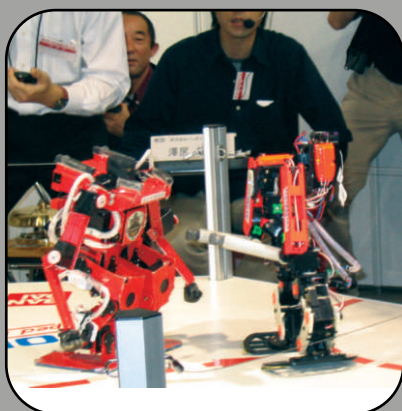
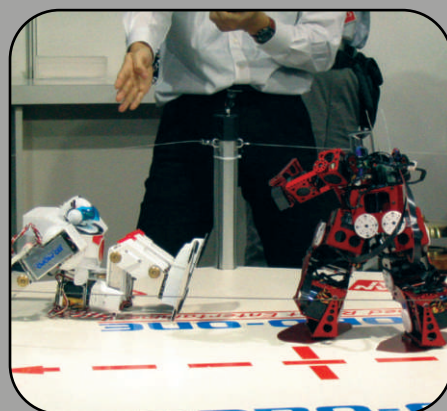
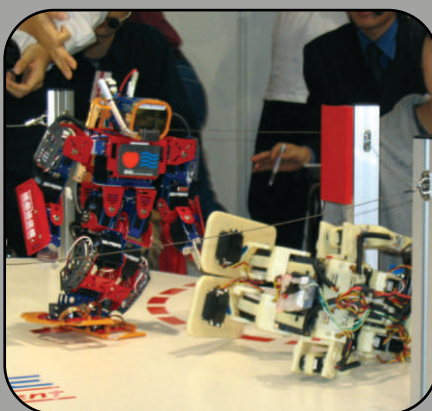


Photo 14





## Robo-One >>>>



each individual degree of motion — it's all pre-programmed.

*Robo-One is one giant leap for robo-kind.*

Androids wrestling and boxing — who could ask for anything more? These robots are as articulate as their corporate sponsored cousins, except they don't have the speech recognition or onboard cameras — but, for 1/20<sup>th</sup> of the price, it's a pretty good exchange.

The competition is broken up into several parts, which are either individual or head-to-head. The individual events are:

- Stair Climbing — The bots do this quite well — it's really cool to watch.

- Boxing / Wrestling — Fighting robots, eat your heart out! There's nothing like watching one android slap another out of the ring.

- Door Opening — Yup. They open doors: So much for your privacy.

- The Dash — Just like high school: Run Robot, Run!

- The Eagle — This is weird. Imagine the mambo, only done by androids.

So, you get the idea that these guys are flexible. They're **amazingly** flexible.

Of course, if you think that they're cool opening doors or doing the mambo — well, you should see them fighting. While they're not as big as

combat robots and don't make the satisfying crashing noises usually found in a combat arena, it's mind-boggling to see these miniature men duking it out right in front of you. These robot melees include sweeping kicks, boxing punches, Tai Kwan Do moves, tumbling rolls, and, of course, a human referee to give a fallen robot a 10 count (in English). What's funny is that, during everything else, they only speak Japanese — I guess the boxing match demands English numerals?

A photo may speak a thousand words, but a video speaks a million. Can't get enough? As a special service for *SERVO* readers, we have several videos of Robo-One fights and demonstrations available online. Just go to <http://robolympics.net/servo/> **SV**

NR-3



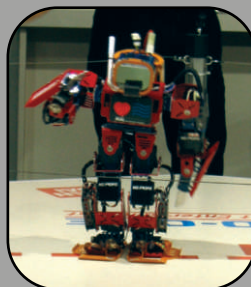
OMNIHEAD



ZAKO



A-Do



DYNAMIZER





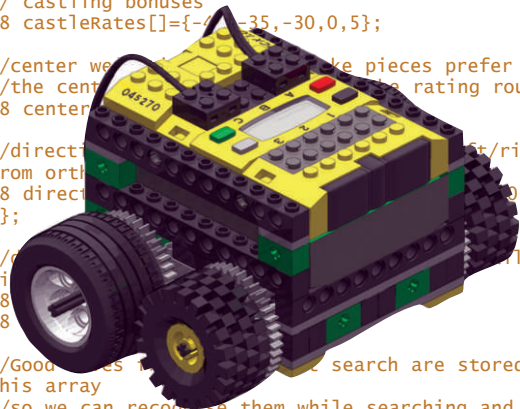
```
// castling bonuses
B8 castleRates[]={-40,-35,-30,0,5};

//center wheel... make pieces prefer
//the center... the rating routine
B8 center...

//direct... left/right
from orth...
B8 direct... 0,1,-
1};

//...
bi...
B8...
B8...

//Good... search are stored in
this array
//so we can recognise them while searching and make
sure they are tested first
```



# LESSONS FROM THE LABORATORY

A  
NEW  
bi-monthly  
column just for  
kids!



## — PART 2 — Building Eddie

by James Isom

**T**his month, we are going to explore what makes a robot a robot. We'll add our first sensor to Eddie (see the February 2004 issue of *SERVO*) and learn how to write a program that allows Eddie to roam around the room by itself.

### What Makes a Robot a Robot?

Robots surround us. You most likely encounter a robot or some kind of robotic system almost everyday in your normal wanderings. They're opening doors for you at the grocery store, spitting out money at the bank, or roaming around alien terrain in outer space. (Okay, maybe you won't run into that one.)

Movies have made them famous and left most people with the impression that a robot must be a gilded android or a patchwork-painted garbage can on wheels that bleeps and whistles and is somehow highly coveted by little, grumpy, hooded beings with glowing eyes! *Boo-tee-nee!* It leaves us wondering exactly what a robot is, anyway.

There is quite a bit of debate over this subject and there are no definite

answers. Over the years, there have been so many things called robots that everyone has a different opinion of what one should be. In my opinion, I think the best definition is the following:

### Ro-bot (n.)

*An automated machine that senses the environment around it and uses that information to make*

*decisions based on its programming to enable it to react appropriately.*

The process a robot goes through in order to sense and react to its environment can be broken down into three simple steps:

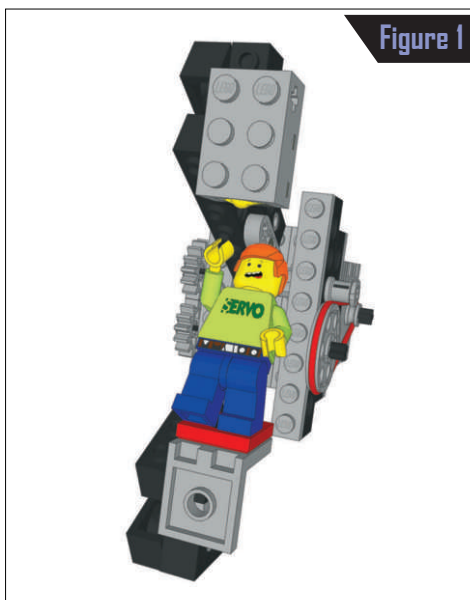
1. Input (Sense)
2. Program (Think)
3. Output (React)

When designing and building a robot, it is important to keep these steps in mind.

How is the robot going to sense its environment? What should it do when it senses something? What instructions do we need to provide to enable it to carry out its goal?

We'll go over all of this again — in more detail — in a bit when we start to program, but, first, we need to build our first sensor for Eddie.

A touch sensor, as the name implies, tells the robot when it is touching something. These are often used on robots in bumpers, grippers, or counting devices (Figure 1). A touch sensor consists of a simple mechanism — in our case, a button — that, when pressed, sends a signal to the RCX. This



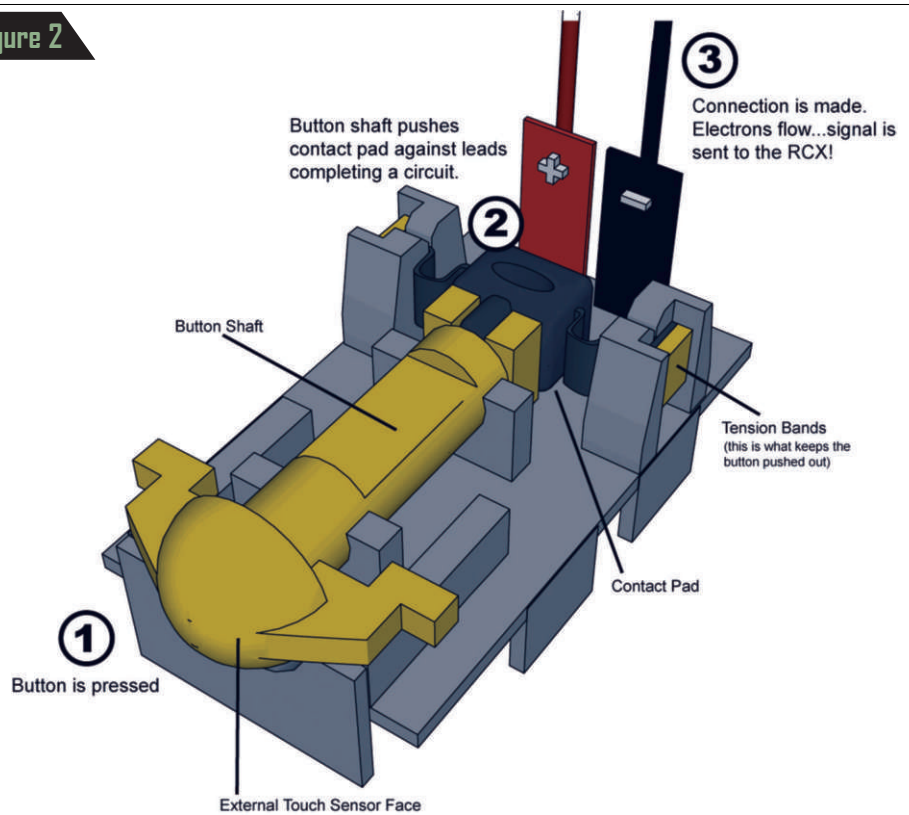
is called a binary sensor because it has two states: on/off, in/out, open/closed, 0/1 — you get the picture.

## How It Works

When the touch sensor is pressed, it completes a circuit that allows an electrical signal to flow back to the RCX. This electrical signal indicates that the touch sensor is pressed in (Figure 2).

Now that we know how a touch sensor works, let's build one for Eddie (actually, two that will function as one). The following steps will show you how to build the sensor. As always, parts from previous steps are turned white to help you distinguish where new parts should be placed. I'll see you on the other side, where we will learn how to program.

Figure 2

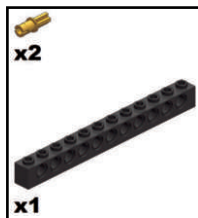


### STEP 1:

Place the two axle pins in the first and last holes of the 1 x 12 beam.



#### Parts:

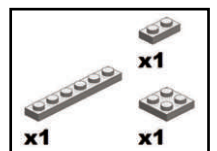


### STEP 2:

Arrange the 1 x 2, 2 x 2, and 1 x 6 plates as shown in the picture. Make sure that one stud of the 2 x 2 and 1 x 2 plate is hanging off the beam.

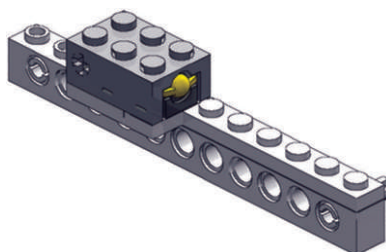


#### Parts:



### STEP 3:

Place the touch sensor on top of the 1 x 2 and 2 x 2 plates.



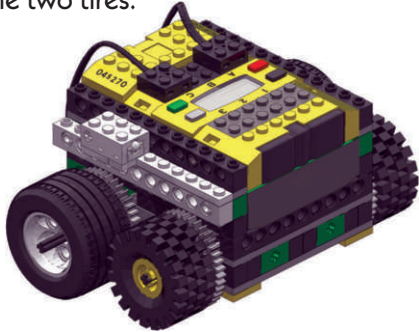
#### Parts:





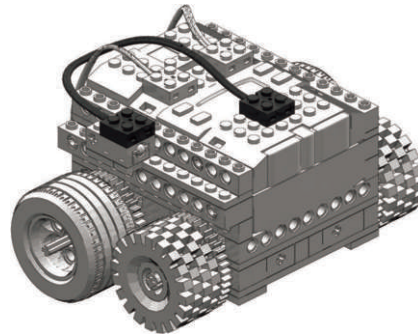
## STEP 4:

Attach what you've built so far to the side of Eddie by placing the two axle pins sticking out of the beam into the green cross hole bricks above the two tires.



## STEP 5:

Attach a short wire to the four studs closest to the touch sensor button. Attach the other end to port 2 (the center, gray sensor pad) on the RCX.

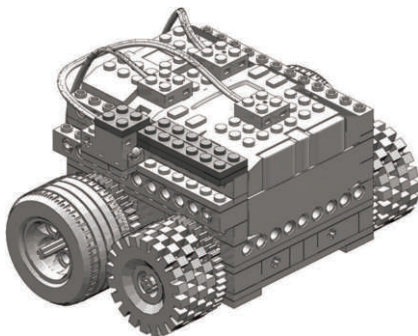


### Parts:

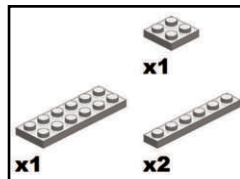


## STEP 6:

Place a 2 x 2 plate on top of the wire connector. Connect the 1 x 6 plates to the top of a 2 x 6 plate and place the assembly on top of the 1 x 12 beam that runs the length of Eddie.

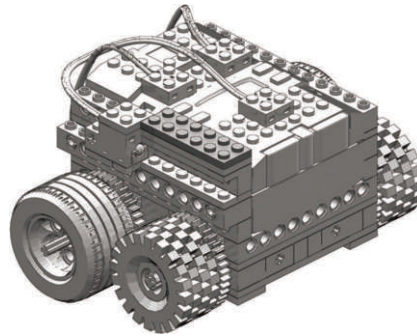


### Parts:



## STEP 7:

Place one more 2 x 6 plate on top of the stack of plates from the previous step.

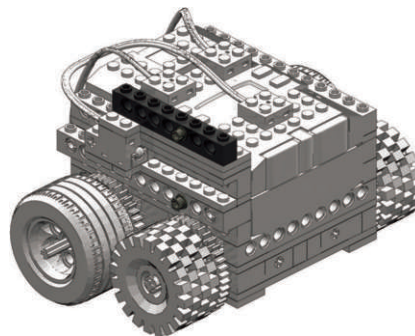


### Parts:

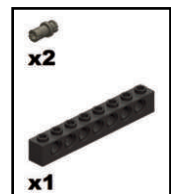


## STEP 8:

Place the 1 x 8 beam on the left edge of the stack of plates. Insert 3/4 pins — short side out — into the third hole from the front on both the top-most beam and the beam just over the front tires.

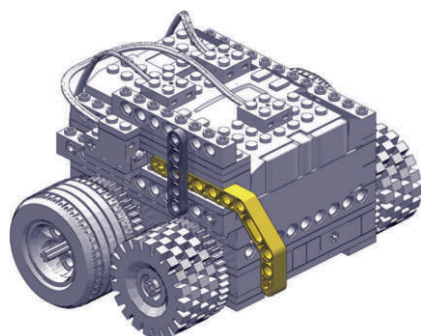


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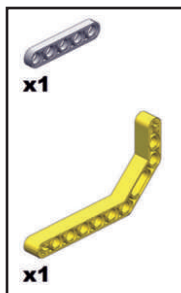


## STEP 9:

Slide the straight end of a double bent lift arm into the gap between the stack of plates and the beam below; secure it by placing a 1 x 5 lift arm onto the two 3/4 pins.

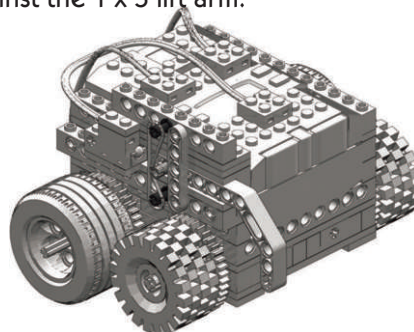


### Parts:

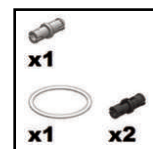


## STEP 10:

Insert a black friction pin in the fourth hole from the front of both beams on either side of the new lift arm and place a gray technic pin in the last hole of the yellow, double bent lift arm. String a white rubber band between the two black friction pins so that the front part of the band pushes the pin against the 1 x 5 lift arm.

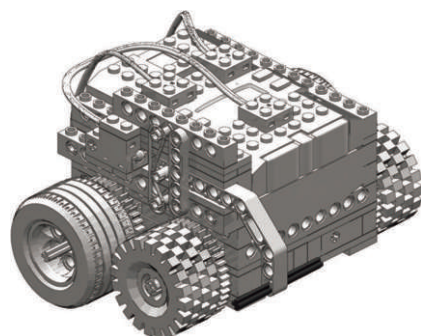


### Parts:

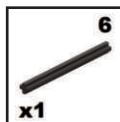


## STEP 11:

Insert a 1 x 6 axle in the bottom cross hole of the yellow lift arm.

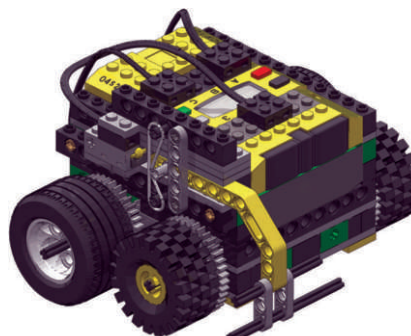


### Parts:

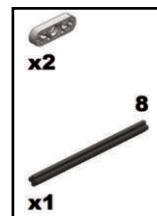


## STEP 12:

Place a 1 x 3 lift arm on either side of the 1 x 6 axle and insert the final 1 x 8 axle in the bottom cross hole.

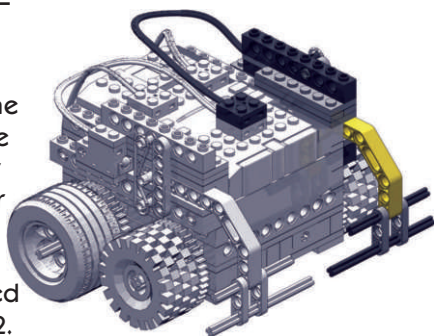


### Parts:



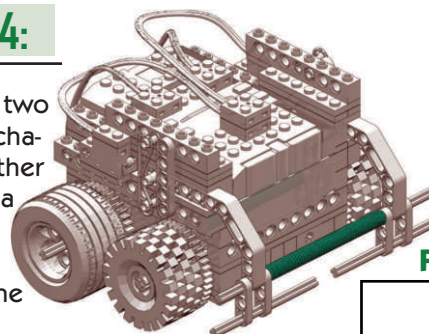
## STEP 13:

Mirror the process for the other side of the robot. Place the wire connector from the sensor on top of the connector already attached to sensor pad 2.



## STEP 14:

Attach the two sensor mechanisms together by placing a piece of tubing between the two inside ends of the 1 x 6 axles.



### Parts:





## Definitions

**Actuator** (n.): A mechanical device that makes something move. Motors, servos, and pneumatic and hydraulic cylinders are all examples of actuators.

**Algorithm** (n.): A set of steps that defines a procedure that achieves a goal or solves a problem. This term is often used in math and was first coined by the Iranian mathematician, Al-Khawarizmi (813-840 C.E.), the father of modern Algebra.

**Binary** (adj.): Consisting of two states.

**Pseudo code** (n.): A simple form of writing down the logical steps to a program using natural language instead of programming language syntax.

Congratulations, you're finished — at least for the moment. We have taken a rather lengthy route to make a single touch sensor for Eddie. The reason for doing this is that I want to cover both single and double touch sensor programming in this article and, as you shall soon see, with a minimum amount of reconfiguring, we can easily switch from a single to a double sensor robot. So, let's get to it.

## Programming Your Robot

There are many ways to program a

robot. The RCX alone has over a dozen programming languages available, ranging from the software that comes with the retail version of the Robotics Invention System (commonly called RIS 2.0) to more traditional environments like C, Forth, and JAVA.

For more information about programming options available for the RCX, have a look at the Fun Robot Stuff page on my website at: <http://robotics.megagiant.com/robotfun.html> under the Mindstorms Programming section.

I will be using Robolab for these tutorials. Robolab was developed at Tufts University and is sold by LEGO's educational division — Pitsco. Here in the US, Robolab is a symbolic programming language that uses icons instead of syntax, allowing the first time programmer to concentrate on the logic of the program without the need to learn confusing syntax. I like it because it's easy to use, cross platform (Mac and PC), and affordable. Even after a couple of years of teaching with it, I'm still learning cool new stuff about it.

Our goal is to write a simple program that allows Eddie to roam around a room, avoiding obstacles. To do this, we need to tell our robot what to do when it runs into an object. We already know that, when a touch sensor is pressed in, it sends a signal to the RCX. Previously, we said that it was important to remember three steps: input, program, output. Our input is the signal from the touch sensor. Our

program will watch for this input and then change the direction of our outputs (the motors — sometimes called actuators) to run an escape routine.

So, what's a program? A program is the set of steps the robot needs to follow in order to complete its goal. All programs — from the computer games you play to the one that tells the Mars rover to examine a specific rock — are just a series of steps. These instructions are sometimes called algorithms. When designing a new algorithm for our robot, it helps to write it out first before we start programming. To start, we could make a brief outline of the steps:

1. Go forward.
2. When you hit something, back up.
3. Turn.
4. Go back to the beginning.

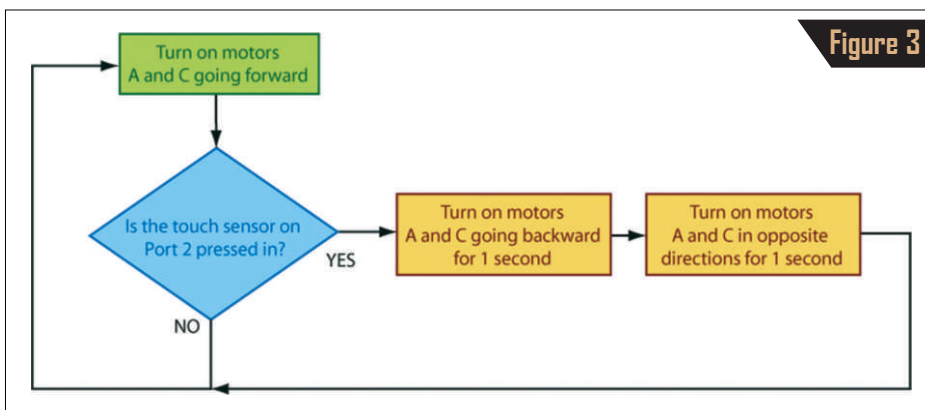
This isn't very specific, but it has the essential set of instructions that our robot needs to achieve its goal. We can get more specific by looking at where our sensors and motors are attached to the RCX. Our touch sensors are connected to sensor port 2 and we have motors connected to power ports A and C.

So, given that information, our outline might look like this:

1. [START] Turn motors A and C on, go Forward, until a Touch Sensor on Port 2 is activated.
2. [BACK UP] Turn motors A and C on, go Backward, for 1 second.
3. [TURN] Turn motors A and C on, in opposite directions, for 1 second.
4. Go back to Step 1.

or different still ...

*turn on motors A and C  
if (touch\_sensor\_2 = pressed) then  
turn on motors A and C backward  
for 1 second turn on motors A and  
C in opposite directions for*



1 second  
else  
repeat forever

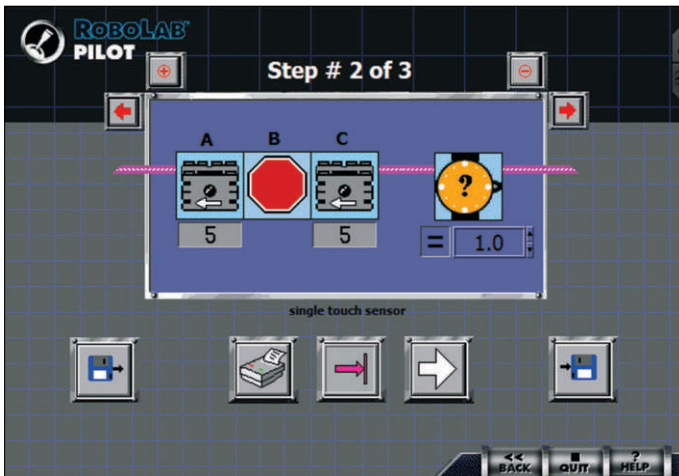
This is all called “pseudo code” and is often used by programmers to get their idea for a program down quickly.

Another way to do this is with a flow chart. Sometimes seeing your program makes it easier to understand. (Figure 3)

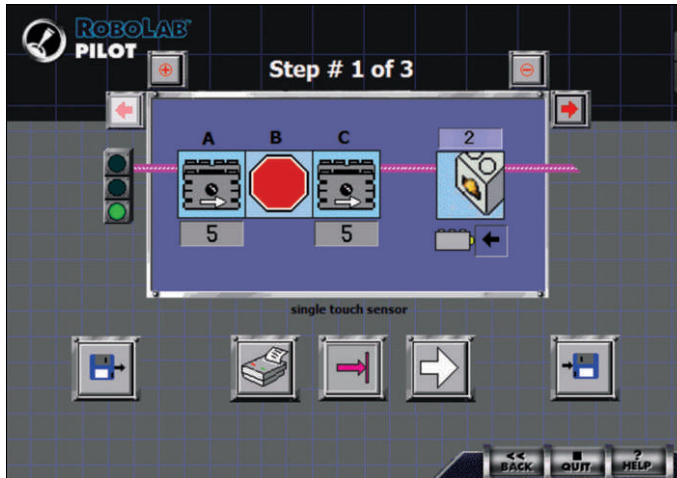
The blue diamond is a decision structure; by answering the question inside of it, the program decides to do one of two things. If the answer is “No,” it goes back to the beginning and keeps going forward. If it’s, “Yes,” it performs an escape routine by backing up and turning before wrapping back around to go forward again.

In Robolab, there are two levels that we are going to be initially concerned with — PILOT and INVENTOR. PILOT programming is based on a series of templates that represent steps in a program. If this is your first time using Robolab, take some time and go through the tutorial exercises that come with the program to learn the basics of using the system. When you’re ready,

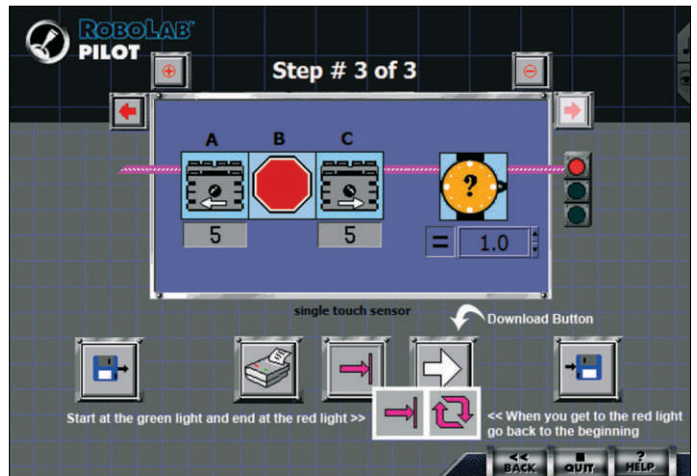
## STEP 2:



## STEP 1:



## STEP 3:



open up PILOT, Level Four, and let’s get started.

According to our pseudo code, our first step is to have the robot go forward until the touch sensor on port 2 is pressed in. Our first step would look like that shown in Step 1.

After the touch sensor is pressed in, the program proceeds to Step 2, which is to back up for one second.

After one second of driving the motors backward, it’s time to make our turn.

In Step 3, the pink arrow with the line following it toward the bottom of the screen means that the program will run from the green light to the red light and stop. If we were to download and run our program now, it would encounter its first object, back up, turn, and then stop. We need to

change the program so that, when it reaches the end of our program, it returns to the beginning. Click on the “run once” arrow and change it to “run continuous.” Now, when our program reaches the red light, it will return to the green light and start all over again.

Download your program. Congratulations, you’ve made a robot that can roam around the room on its own!

After watching Eddie roam a bit, you will notice that he always turns the same way. This usually works to get him out of a tight spot, but wouldn’t it be better if we used both sensors, so that, if the right one was hit, he would back up and turn left and visa versa?

Remove the tubing that connects the two bumpers and, looking at the front of Eddie, move the right side touch sensor’s connection from sensor pad 2 to sensor pad 1. Do the same for the left side, but move the wire from pad 2 to pad 3. We now have a double touch sensor robot.

Your robot should look like the one in Figure 4.

Let’s take a quick look at what the pseudo code might look like for this

Run Once



Run Continuous





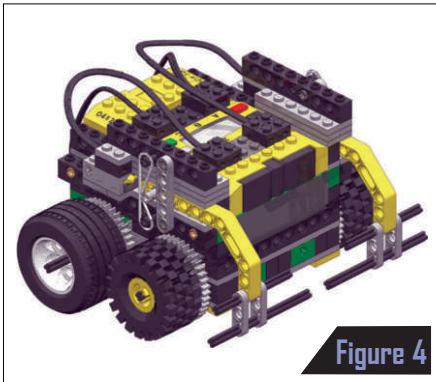


Figure 4

new program.

go forward  
 if touch sensor 1 is pressed, then  
 go backward for 1 second,  
 turn left  
 if touch sensor 3 is pressed, then  
 go backward for 1 second,  
 turn right  
 repeat forever

The flowchart would look like that in Figure 5.

Open up Inventor, Level Four, and build the following program (shown in Figure 6).

Notice that this looks a lot like our flow chart. Download and run the program.

Eddie now bounces off each object and turns away from it. Congratulations! You have made a more efficient navigation program. Programmers love efficiency and are always trying to do the most work with the simplest program. Do you see a way to make our program more

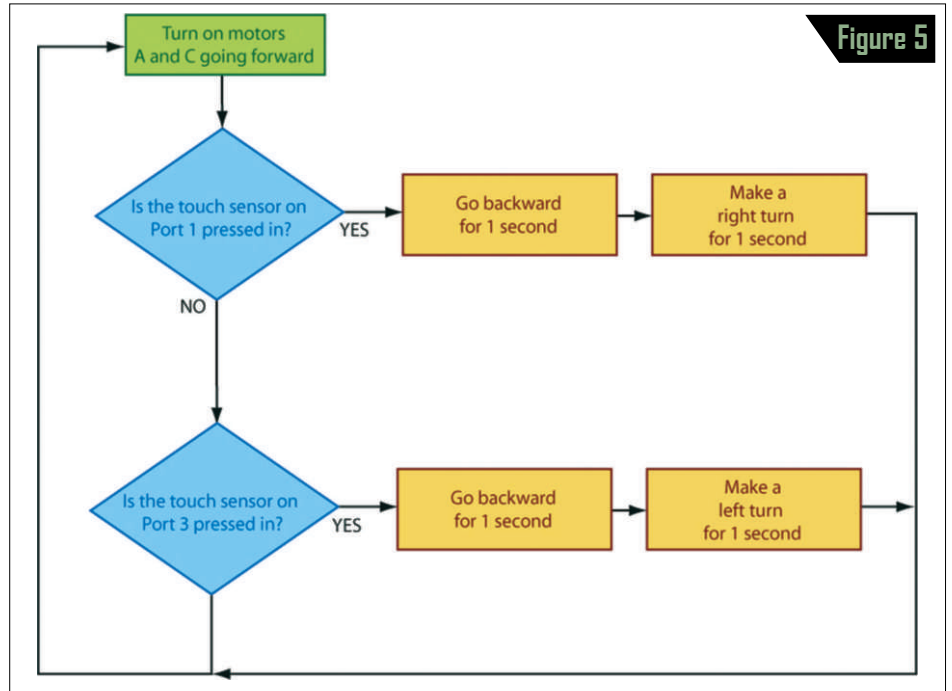


Figure 5

efficient? Can you use fewer icons or simplify it even further? Give it a try and send me your results.

Next time, we'll take a look at light sensors and tackle some more advanced programming techniques. **SV**

## Links

How Robots Work:  
<http://electronics.howstuffworks.com/robot1.htm>

Robolab at Tufts University:  
<http://www.cceo.tufts.edu/graphics/robolab.html>

Pitsco — LEGO Educational Division:  
[www.pitsco-legodacta.com](http://www.pitsco-legodacta.com)

## Author Bio

James Isom is a part-time robotics teacher and general all-around geek. He has taught robotics to children and teachers in the US and abroad.

His website with other additional goodies (including the MLCAD file of this robot) can be found at [www.theroboticslab.com](http://www.theroboticslab.com)

He can be reached at [james@megagiant.com](mailto:james@megagiant.com)

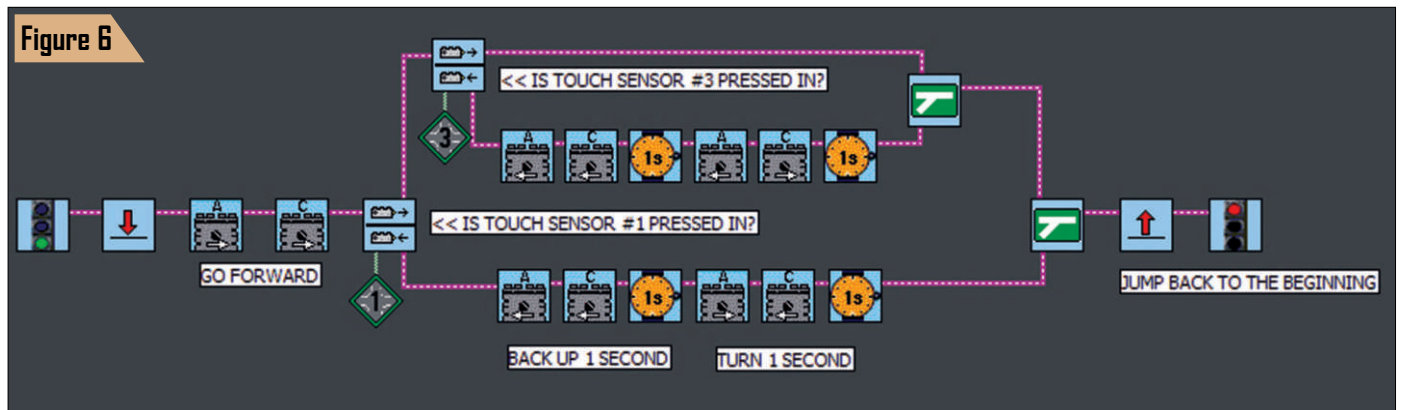


Figure 6

# Measuring Dust on the Red Planet

## *Muscle Wires on Mars*

by Roger G. Gilbertson

### Elements of Chance

Every day, we wake to a world of chance. Anything can happen and, usually, we work hard to keep things from happening — bad things, unexpected things, disruptive things, or things that prevent us from performing tasks we've agreed to do or think we must do. In this world of chance, where luck favors the prepared, sometimes letting chance work its magic permits amazing things to happen.

In the summer of 1994, I opened myself to chance and eventually found myself participating in a series of events that would send a hair-like piece of a special wire from a drawer in the closet of my apartment to the surface of another world — to the Red Planet, Mars.

### To Boldly Go

I have been a member of the Planetary Society — the public space advocacy group founded by Carl Sagan, Bruce Murray, and Louis Friedman — since its inception in 1980. In 1992, an issue of their publication, *The Planetary Report*, described the work of Dr. Edward Belbruno and his novel way of sending spacecraft to other worlds using much less energy than previously possible and, therefore, at a much lower cost [1].

As I'd always been a fan of low-cost space travel, I wrote to Belbruno with some questions regarding his work. We

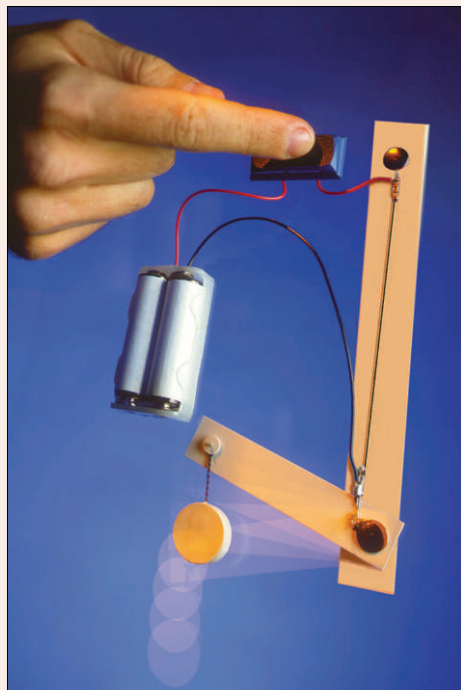
had a conversation via Email about his orbital designs and then he switched topics to a new and bigger interest — sending robotic spacecraft to nearby star systems and receiving data back from them within a human lifetime [2]. Belbruno had planned a conference on the issues surrounding this topic and invited me to attend.

At that time, I lived the life of a struggling entrepreneur, performing various consulting jobs for companies — both large and small — and designing applications with nickel-titanium shape memory alloys (SMAs) — thin wires that shorten when electrically heated. I had recently started a mail order business — selling a selection of Muscle Wire® SMA kits and a book that I'd written on the subject — to help even out the irregular highs and lows of a consulting income. Two part-time employees helped me process and ship orders from the spare room of my two-bedroom apartment. The prospect of taking time off to travel to New York City for something as far out as interstellar travel simply did not have a place in my business plan.

Dr. Belbruno proved a persistent salesman, though. He enlisted my participation in building models of his interstellar satellite designs (a ring about 2 m across, weighing less than a kg total, and covered in microscopic instrumentation), arranged for low-cost dormitory housing at New York University (the host venue for the conference), and offered me the opportunity to give a presenta-



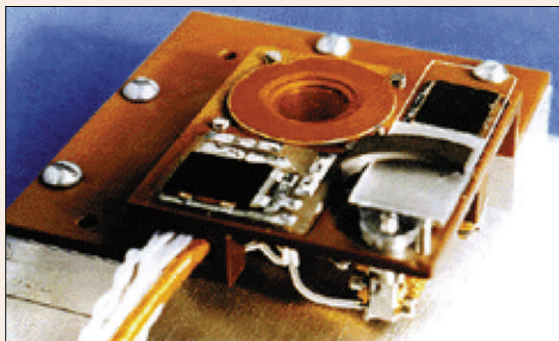
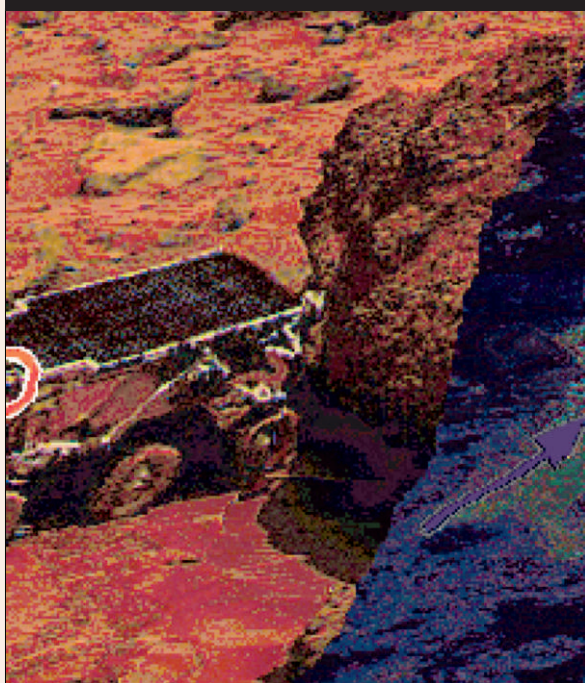
# Measuring Dust on the Red Planet



**Figure 1.** The Lever Arm Demonstration. It operates much like this project, but it uses a thin elastic band to return the lever to its lower position, enabling horizontal operation.

tion on my work with shape memory alloys. So, as I could now view the trip as a marketing expense, I took a chance and agreed to attend [3].

**Figure 3.** MAE on Mars aboard the Sojourner Rover.



**Figure 2.** The Materials Adherence Experiment or MAE.

## Among the Stars

In short, the conference proved to be astounding. Given the sponsorship of the Planetary Society, New York University, and the United Nations, Dr. Belbruno had attracted a list of attendees that shone with some of the brightest stars in the aerospace sky. I sat, an invisible red dwarf, in rapt attention to presentations by luminaries that included Dr. Robert L. Forward (interstellar travel visionary), Dr. Seth D. Potter (space power satellite research), Dr. Robert Zubrin (later to found the Mars Society), Dr. Brice Cassenti (United Technologies Research Center), Dr. David Brin (scientist and award winning science fiction author), the mysterious Dr. Claude Poher from CNES (the French space agency), and many others [4].

I prepared my talk with John D. Busch, then of TiNi Alloy Company, one of my consulting venues. Entitled "A Survey of Micro-actuator Technologies for Future Spacecraft Missions," we endeavored to gather and compare all known ways of creating motion from electricity, with attention to how they might be used on lightweight interstellar spacecraft [5].

My presentation went well, with the various examples and working devices proving of interest to the attendees. In particular, Dr.

Geoffrey Landis — from NASA's Lewis (now Glenn) Research Center — studied a lever arm device operated by a short length of Muscle Wire; I had originally developed the arm for use on an overhead projector during my talk. I included this lever arm as a project in my *Muscle Wires Project Book* and Dr. Landis arranged to order a copy of it and some sample wire for a project he

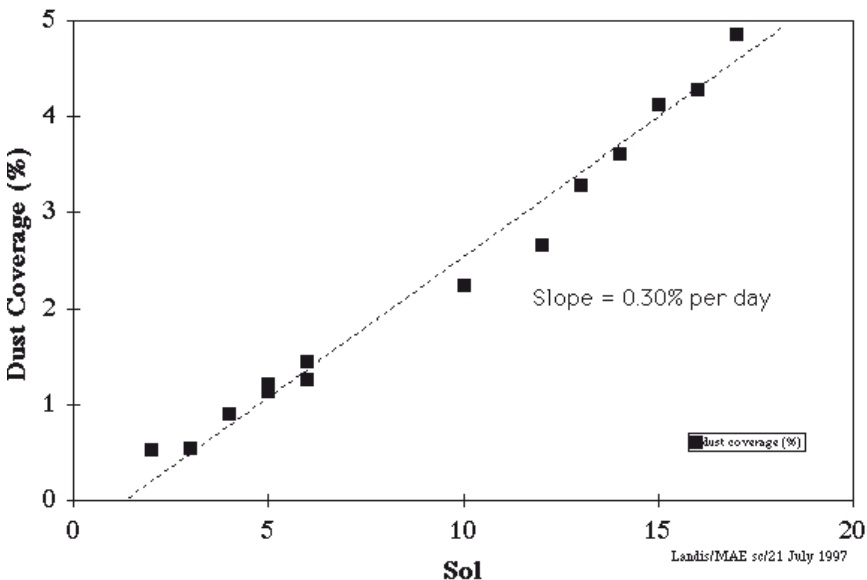
had in mind.

## Faster, Better, Cheaper (and From My Closet!)

In the 1970s, NASA performed a great deal of pioneering research into using SMAs for space applications, but with the catastrophic loss of the billion dollar Mars Observer mission due to a leaky fuel valve, the new NASA administrator, Dan Goldin, installed the mantra of, "faster, better, cheaper." For the first time in many years, NASA researchers were encouraged to actually try new things and fly them into space. Suddenly, new opportunities were found for SMAs to travel beyond the Earth on US space missions.

Back in Ohio, Geoff Landis and his research partner, Phillip Jenkins, began crafting a small, Mars-worthy instrument called the Materials Adherence Experiment (MAE). It consisted of a thin glass plate, positioned above a small solar cell, with a 3 cm (1.2 inch) length of Flexinol 150 LT Muscle Wire. The wire provides an extremely small, lightweight, and low-power source of motion. As thin as a human hair, the specially processed nickel-titanium wire has a breaking strength stronger than stainless steel and, when powered with a small electric current, it exerts a force capable of lifting 330 grams (over 11 ounces) in Earth's gravity.

When activated, Muscle Wire pulls the glass plate to the side, exposing the solar cell to full sunlight. Then, with power removed from the wire, it relaxes



**Figure 4.** Results of MAE Measurements, showing dust build-up on the Sojourner Rover's top surface. These measurements affected decisions in the design of the Mars Exploration Rovers — Spirit and Opportunity — which started to explore Mars in January of this year.

and permits the glass to return to its position over the solar cell. Any dust on top of the glass reduced the amount of light reaching the solar cell by a small amount and, by comparing the signal of the direct sunlight to the signal through the dusty glass plate, Landis and his team hoped to determine the rate of dust build-up on the top of the glass slide.

The MAE instrument rode aboard the Mars Pathfinder Sojourner robot, positioned on the top corner of the robot's flat solar panel. Since dust build-up greatly reduces the effectiveness of the solar panels, excessive dust levels could possibly bring an early end to a solar-powered mission on the surface of Mars, but how quickly dust accumulated on Mars had never been measured before.

Mondo-tronics shipped the Flexinol wire to NASA from the same supply that serves our hobbyist, student, and experimenter customers — right out of the file cabinet in my spare bedroom closet. Since we knew where it might be going, all three of us touched the wire before sealing it in its envelope, wishing it good luck. Launched in December of 1996, the Mars Pathfinder and the Sojourner Rovers touched down on Mars on July 4,

1997. The mission proved to be a spectacular success; the Rover worked wonderfully and the MAE performed perfectly over the life of the mission, measuring the build-up of Martian dust on the Rover's top surface.

For more on the MAE instrument and its results see: <http://powerweb.grc.nasa.gov/pvsee/experiments/MAE.html>

## Project — Basic Muscle Wire Lever Arm

In this device, a length of Muscle Wire moves a lever, which lifts a weight. This project shows how simple levers can transform the small motion of a Muscle Wire into a weaker, but much larger motion. A device like this, presented at the Robotic Interstellar Flight conference in 1994, led to the development of the Mars-worthy lever arm device in the Materials Adherence Experiment carried aboard the Pathfinder Sojourner Rover in 1997.

### Construction:

Assemble the Muscle Wire, crimps, staples, and connecting wires as

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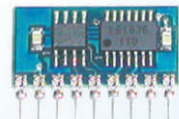


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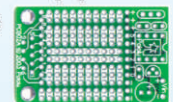


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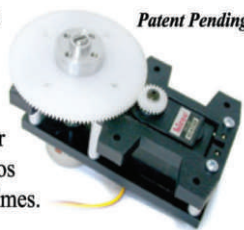




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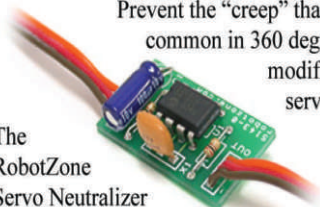


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## Measuring Dust on the Red Planet

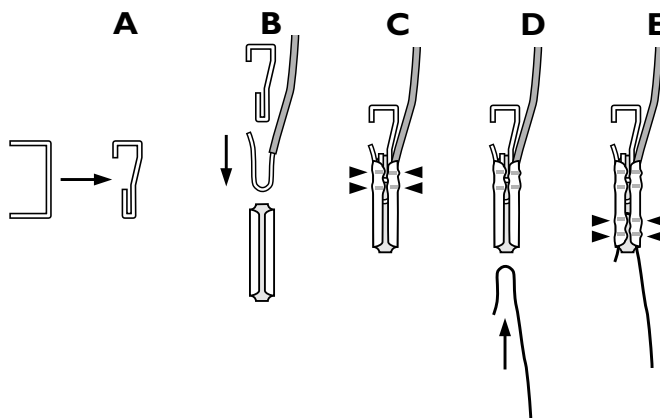


Figure 5. Basic Crimp and Wire Connection.

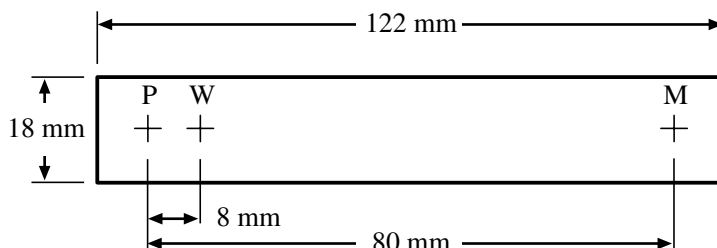


Figure 6. Lever Arm Pattern, actual size.

shown in Figure 5. This crimp, staple, and wire method provides both mechanical and electrical connections to a Muscle Wire. N-scale track connectors for model railroads are inexpensive

and easy to crimp. Bend staple (A), insert it and the conductive wire into connector (B), and crimp it with pliers (C). Add Muscle Wire to other end (D) and crimp it for a solid mechanical and electrical contact (E).

### Parts List — Basic Muscle Wire Lever

| Quantity | Description                                                  |
|----------|--------------------------------------------------------------|
| 1 each   | Muscle Wire, 150 mm dia, 10 cm long                          |
| 2 each   | Crimp (N-scale rail joiner, brass tube, etc.)                |
| 2 each   | Staple, bent as shown                                        |
| 2 each   | Thin connecting wire (30 gage wrap wire or similar)          |
| 3 each   | Tack                                                         |
| 1 each   | Cardboard base (corrugated, about 12 x 23 cm or 4.5 x 9 in.) |
| 1 each   | Cardboard lever (see Figure 6)                               |
| 2 each   | Battery, AA size                                             |
| 1 each   | Battery holder, 2 x AA, 3 volt                               |
| 12 each  | US penny coins (or other 30 gram mass)                       |
| 1 each   | Small plastic bag                                            |
|          | Tape, transparent                                            |

Photocopy the lever arm pattern (Figure 6) and glue it to thin cardboard (poster board or an empty cereal box). Cut out the cardboard lever and tack the free end of the Muscle Wire to the lever at the point labeled "W." Note that this tack points outward from the cardboard base.

Tack or push-pin the lever to the cardboard base at the point labeled "P." Position the pivot tack to take up any slack in the Muscle Wire and so that the lever points downward to four o'clock.

Place the coins in the bag and, using another tack pressed through from the back, hang it at the point labeled "M" (see Figure 8). Tape the connecting

wires to the base with some slack so the lever can move freely.

Using two AA batteries in the battery holder, briefly apply power to the connecting wires (about one second). The Muscle Wire should contract and move the lever about 30 degrees (above the three o'clock point). Remove power immediately and let the wire cool and relax.

#### How It Works:

The powered Muscle Wire contracts and lifts the lever arm. Since the distance from "P" to "M" is 10 times the distance "P" to the "W," the force exerted by the 30 gram mass is 10 times greater at the "W" point.

The wire lifts the lever about 5 mm at the "W" point, which becomes about 10 times or 50 mm of motion at "M." Note that multiplying the force times the lever length is an approximation that works only with the lever at or near 90° to the wire. Since the lever moves in an arc, use trigonometry to calculate its performance with other angles and positions.

#### Variations:

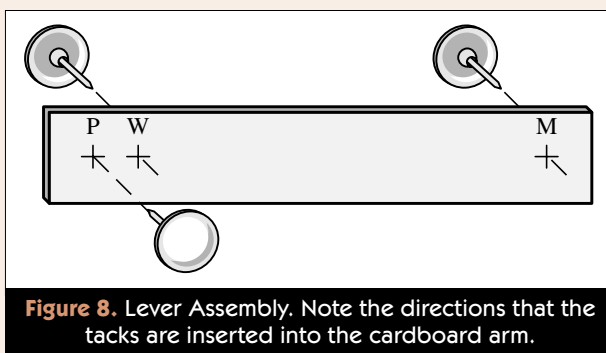
- Mark the start and end points of the lever's motion on the cardboard. Measure the distances and calculate the wire's percentage of contraction. Move the tacks so the lever starts at the one o'clock position. How much does it move?
- Increase the 30 gram mass by adding one coin at a time. At what point does the device fail? What parts are likely to fail and why? How would better materials and construction help?
- Observe your own arm and notice how the muscle in your upper arm contracts to lift your forearm. Can you locate the "P" and "W" points on your elbow joint? Estimate the percentage that your upper arm muscle must contract to lift your wrist by 10 cm.
- Given your above estimate, if you hold a 1 kg mass in your hand, how much force does it exert at the point where the muscle connects to the

forearm (at the "W" point)? From *Muscle Wires Project Book*, Third Edition, by Roger G. Gilbertson. Published by Mondo-tronics Inc., ISBN 1879896133.

## Our Cosmic Shooting Gallery

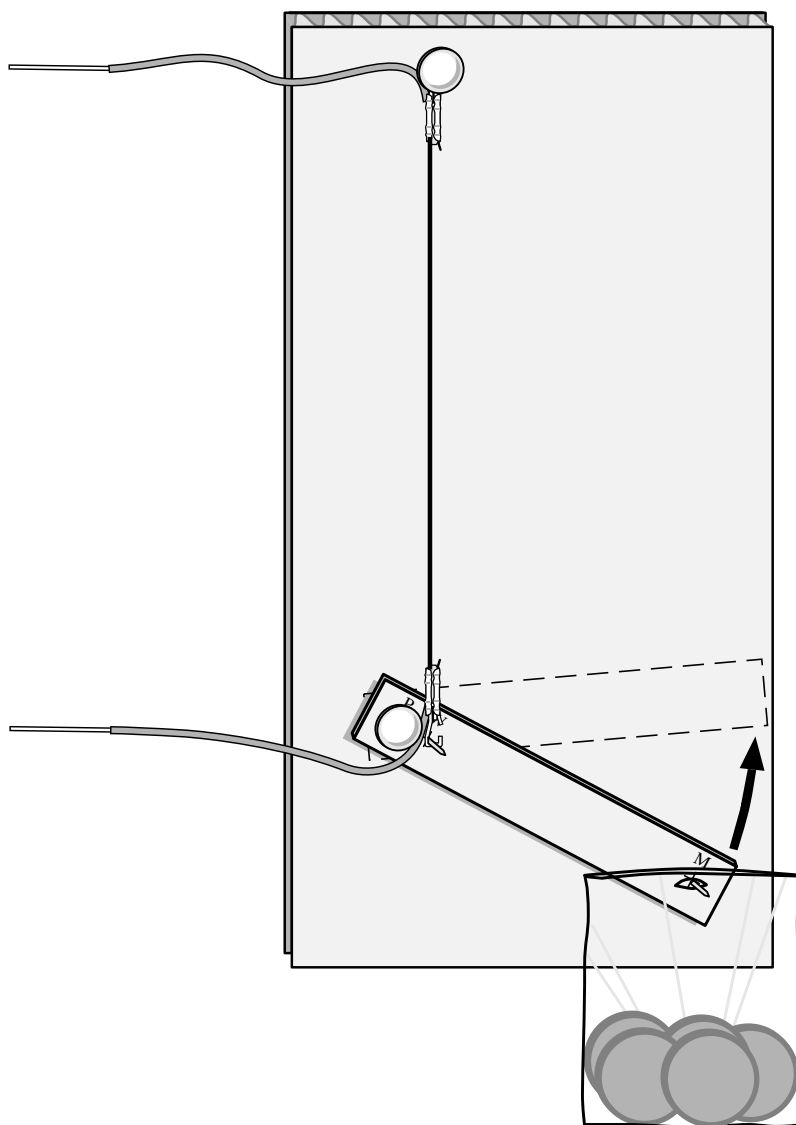
The dinosaurs never knew what hit them, but we know for certain that our

mother Earth will inevitably find herself in the sights of a cosmic projectile capable of again extinguishing nearly



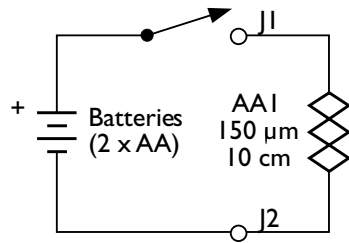
**Figure 8.** Lever Assembly. Note the directions that the tacks are inserted into the cardboard arm.

**Figure 7.** General Assembly for the Basic Lever. When powered, the wire contracts about 5 mm and raises the end of the lever by about 50 mm.





# Measuring Dust on the Red Planet



**Figure 9.** Basic Schematic. Points J1 and J2 show where the batteries and Muscle Wire connect, acting as a switch. The accordion-like symbol for the shape memory alloy wire element reflects both its internal resistance (which generates heat from the passing of an electric current) and its ability to contract.

all of her major life forms. Though we may not face this threat for years, centuries, or even millennia to come, human beings represent the first species on Earth — and perhaps the last — capable of identifying and preventing such a catastrophe.

With resolve and a modest, but long-term investment of resources, we can identify and categorize the various potential threats and develop methods

of deflecting, destroying or even capturing the potentially menacing objects [6].

Given the present status of our space program, many people ask if we still have what it takes to keep sending humans and robots to other worlds, but we have no choice. If we stop our efforts to become masters of interplanetary space, then we accept extinction as our ultimate fate. Aided by our increasingly sophisticated robotic extensions, the human race *must* assume the role of “Protectors of the Biosphere.”

In this world of chance, what greater role could we play than to awake one morning to the threat of a biosphere destroying impact and to know that we can and will prevent it from happening. By comparison, all of our other concerns of the day fade to insignificance.

Build more robots! **SV**

**Flexinol is a trademark of Dynalloy, Inc., and Muscle Wires is a registered trademark of Mondo-tronics, Inc.**

## For Your Info

A second part of this article will present a more elaborate version of the Simple Lever Arm device and will include a photo sensor to measure the buildup of dust on your desktop, much like the MAE's manner of functioning.

## About the Author

In college, Roger G. Gilbertson studied engineering, robotics, and the walking patterns of living creatures. In 1987, he co-founded Mondo-tronics, Inc., to explore the commercial applications of Shape Memory Alloy wires. In 1995, he launched **RobotStore.com**, the Internet's first commercial robotics site. Mondo-tronics' Robot Store continues to lead the field in presenting the best and most innovative new robot products for students, educators, hobbyists, and experimenters. Roger lives and works in Marin County, CA, where space awaits just 100 miles straight up, but some people already think we're there.

## FOOTNOTES

1. Edward Belbruno, “Through the Fuzzy Boundary: A New Route to the Moon.” *The Planetary Report*, May/June 1992, pp. 8-10. This method relied on complex mathematics very different from those used in, for example, the Hohmann transfer orbit used on the Apollo missions to reach the Moon. It has the trade-off of longer flight times, but permits robotic missions to travel using much less fuel (i.e., less cost) or to take a larger payload using the same amount of fuel. Belbruno's methods were used successfully on Japan's Muses-A lunar spacecraft (later renamed Hiten) and the European Space Agency's Smart-1 mission.

2. Basic concept: Make the spacecraft very lightweight and send it very fast — up to 90% of the speed of light. A 1 kg satellite would be accelerated from Earth's orbit using a particle beam (like launching a pie tin on the stream from a

fire hose). It would reach 0.9 c in a matter of days, about when it crossed the orbit of Jupiter, and could pass through the Alpha Centauri star system less than five years later. The data beamed back to Earth from this encounter would arrive after another four years. Given the nature of these challenges, it might be best to launch a fleet of them at a given target — sort of a robotic shotgun blast — to ensure that some of them reach their target and pass close enough to the target star to gather sufficient energy for reporting the findings of the entire armada back to Earth. As of yet, the amount of energy required to accelerate 1 kg to 0.9 c exceeds our present capabilities, but not by much.

3. “Practical Robotic Interstellar Flight: Are We Ready?” August 29-September 1, 1994, New York University and The United Nations, New York City. Sponsored by the Planetary Society.

4. It amazes me now to realize how many of the attendees are not only accomplished aerospace innovators, but how many have written noted and well-received works of science fiction, including Forward, Zubrin, Brin, and Landis.

5. First published in *The Journal of The British Interplanetary Society*, Vol. 49, pp. 129-138, 1996. A March 2003 version of the paper in PDF format may be downloaded from **www.RobotStore.com/support.asp** at the link labeled, “Actuator Method Survey.” The list of methods includes: electromagnetic, electrostatic, thermomechanical, phase change, piezoelectric, shape memory, magnetostriuctive, electrorheological, electrohydrodynamic, and diamagnetism.

6. See **www.spaceguarduk.com** and **www.b612foundation.org** for starters.

# EVENTS CALENDAR



Send updates, new listings, corrections, complaints, and suggestions to: [steve@ncc.com](mailto:steve@ncc.com) or FAX 972-404-0269

*April is by far the busiest month of the year for robot builders; competitions are occurring throughout the month. The Dallas Personal Robotics Group will start things off on April 3<sup>rd</sup> in Dallas, TX with RoboRama 2004. Next up is the annual Micro Air Vehicle (MAV) Competition, where the smallest flying robot will take the prize. This year's MAV event is at the University of Arizona in Tucson. A week later, the national championships for the FIRST Robotic Competition (FRC) and the FIRST LEGO League (FLL) will be held in Atlanta, GA.*

*From that point through the rest of the month, there's at least one competition every day — somewhere in the world. Many are well known events, such the CMU Mobot Race, RoboRodentia, and the SAE Walking Machine Challenge. Read on for the full list of April events — there are just too many to describe in a couple of paragraphs!*

— R. Steven Rainwater

For last minute updates and changes, you can always find the most recent version of the complete Robot Competition FAQ at Robots.net: <http://robots.net/rcfaq.html>

## April

3

### DPRG Roborama

The Science Place, Dallas, TX  
Autonomous robots competing in all of the usual events: quicktrip, t-time, and can-can.  
[www.dprg.org/competitions/](http://www.dprg.org/competitions/)

9-11

### Micro Air Vehicle Competition

University of Arizona, Tucson, AZ  
A variety of events for tiny, flying robots, including smallest MAV surveillance, MAV endurance, and — new this year — an ornithopter competition.  
[www.engr.arizona.edu/MAVcompetition/](http://www.engr.arizona.edu/MAVcompetition/)  
[www.mae.ufl.edu/mav](http://www.mae.ufl.edu/mav)

### 15-17 FIRST Robotics Competition

Georgia Dome, Atlanta, GA  
This national championship event for the FIRST student robot competitions is the largest FIRST event of the year and is open to the public.  
[www.usfirst.org/](http://www.usfirst.org/)

16

### Carnegie-Mellon Mobot Races

Wean Hall, CMU, Pittsburgh, PA  
The 10<sup>th</sup> annual occurrence of the now famous CMU Mobot race — autonomous robots race to complete a complex course, passing through 18" finish gates along the way.  
[www.cs.cmu.edu/~mobot/](http://www.cs.cmu.edu/~mobot/)

### 16-17 OTEA National Robotics Competition

Veterans Memorial Coliseum, Marion, OH  
This contest is intended to replace the defunct RI/SME Robotics Challenge. It includes several autonomous robot events, as well as a radio controlled event for beginners.  
[www.ohiotech.org/competitions.html](http://www.ohiotech.org/competitions.html)

17

### RoboRodentia

California Polytechnic State University, San Luis Obispo, CA  
This is something like a micromouse event, except that, in addition to navigating the maze, mice have to pick up balls and return them to a "nest."  
[http://ieee.ee.calpoly.edu/ieee\\_cs/](http://ieee.ee.calpoly.edu/ieee_cs/)

17

### UC Davis Picnic Day MicroMouse contest

University of California, Davis Campus, CA  
Every year, UC Davis has a campus wide event, known as Picnic Day, and every Picnic Day includes the annual micromouse contest. The event follows standard micromouse rules.  
[www.ece.ucdavis.edu/~ieee/umouse/umouse.html](http://www.ece.ucdavis.edu/~ieee/umouse/umouse.html)

18

### ChiBots Robotics Contest

Schaumburg Public Library, Schaumburg, IL  
Line following, advanced line following, solarrollers, and the infamous pound of wood mini-sumo challenge.  
[www.chibots.org](http://www.chibots.org)

18

### Trinity College Fire Fighting Home Robot Contest

Trinity College, Hartford, CT  
An autonomous robot must move through a mock house, locate a fire, and extinguish it. This year's contest will be the first without Jake Mendelssohn



at the helm. He will be missed.  
[www.trincoll.edu/events/robot/](http://www.trincoll.edu/events/robot/)

## 20-22 DTU RoboCup

Technical University of Denmark,  
Copenhagen, Denmark  
Imagine your typical line following contest. Now, add forks in the line, ramps, stairs, gaps in the line, shifts from indoor to outdoor lighting, reversals of line shading (white to black), and 50 cm "gates" through which the robot must pass.  
[www.iau.dtu.dk/robocup/about\\_robocup.html](http://www.iau.dtu.dk/robocup/about_robocup.html)

## 21-24 BattleBots IQ

The Four Seasons Center, Owatonna, MN  
Student-built radio controlled vehicle combat.  
[www.battlebotsiq.com/](http://www.battlebotsiq.com/)

## 23-24 Steel Conflict

Anaheim, CA  
Radio controlled vehicle combat.  
[www.steelconflict.com/](http://www.steelconflict.com/)

## 24 RoboFest

Lawrence Technological University, Southfield, MI  
A competition and exhibition of autonomous LEGO robots. Designed to spur student interest in science, engineering, programming, and technology.  
<http://robofest.net/>

## 24 The Tech Museum of Innovation's Annual Tech Challenge

San Jose Civic Auditorium, San Jose, CA  
This year's event is Pick a Pike — the robots must find and collect a plastic fish in Lake Davis and return it to shore within three minutes.  
[www.thetech.org/tech\\_challenge/](http://www.thetech.org/tech_challenge/)

## 24-25 Melexis Safety Trophy

Leuven, Belgium  
Autonomous cars navigate a scale traffic environment, competing for 10,000 euros worth of prizes.  
[www.trophy.melexis.com/](http://www.trophy.melexis.com/)

## 25 MonsterMakers Animatronics Workshop

The MonsterMakers, Cleveland, OH  
One day workshop covers servo animatronics, latex skin technology, moldmaking, vacuumforming, mechanical applications, R/C, and automation.  
[www.monstermakers.com](http://www.monstermakers.com)

## 28 Alcabot

University of Alcala, Madrid, Spain  
Events include Dredges, Sprinters, Labyrinth, and Free Test. HISPABOT is being held at the same location on the following day.  
[www.depeca.uah.es/alcabot/](http://www.depeca.uah.es/alcabot/)

## 28 SAE Walking Machine Challenge

Union College, Schenectady, NY  
This is the collegiate level contest for autonomous and tele-operated walking robots. For 15 years, some of the most innovative robot designs around have turned up at this event.  
[www.sae.org/STUDENTS/walking.htm](http://www.sae.org/STUDENTS/walking.htm)

## 29-30 HISPABOT

University of Alcala, Madrid, Spain  
Autonomous robots will be competing in events with names like Trackers and Speeders, as well as conventional fare, such as autonomous sumo and maze running.  
[www.depeca.uah.es/alcabot/hispabot2004/concurso\\_eng.htm](http://www.depeca.uah.es/alcabot/hispabot2004/concurso_eng.htm)

## 30 Online Simulated Robot Judo Contest

Online, by Cyberbotics  
Using the Webots software, competitors can program simulated humanoid robots to engage in judo competitions. Entry deadline is April 30, 2004.  
[www.cyberbotics.com](http://www.cyberbotics.com)

## May

## 6-16 Edventures Robotics Challenge

This is a rather unique event. The challenge is not against other robot builders. Each team attempts to complete the challenge and provides digital photos to the judges who make a final determination. There is not a single winner, in the traditional sense.  
[www.edventures.com/erc/](http://www.edventures.com/erc/)

## 14 SPURT

Rostock-Warnemunde, Germany  
SPURT stands for School Projects Using Robot Techniques. Special autonomous SPURT racing robots race around a special SPURT track.  
<http://spurt.uni-rostock.de/>

## 15 Atlanta Robot Rally

SciTrek Museum, Atlanta, GA  
The annual Robot Rally includes a vacuuming contest, mini-sumo, and a unique open contest in which contestants provide their own goals.  
[www.botlanta.org/Rally/](http://www.botlanta.org/Rally/)

## 15 Western Canadian Robot Games

Southern Alberta Institute of Technology,  
Alberta, Canada  
Traditional and BEAM events.  
[www.robotgames.com/](http://www.robotgames.com/)

## 18-20 Singapore Robotic Games

Singapore Science Centre, Republic of Singapore  
This one includes a wide range of events, from micromouse and sumo to pole balancing and wall

climbing.  
<http://guppy.mpe.nus.edu.sg/srg/>

## 21-23 Eurobot

La Ferte Bernard, France  
Each year, a different event is offered. This year, it's robot rugby.  
[www.anstj.org/robot/concours/eurobot/garde\\_en.html](http://www.anstj.org/robot/concours/eurobot/garde_en.html)

## 28-31 BattleBots

Mare Island (Vallejo), CA  
If you're into watching radio controlled vehicles bump into each other, this is the big one.  
[www.battlebotsiq.com](http://www.battlebotsiq.com)

## June

### 4-6 RoboJoust

Las Vegas, NV  
Another radio controlled vehicle demolition derby.  
[www.robojoust.com/](http://www.robojoust.com/)

### 6 PDXBOT

Smith Center Ballroom, Portland State University, Portland, OR  
Lots of events, including mini-sumo, micro-sumo, Japan sumo, line following, walkers, and a talent show.  
[www.portlandrobotics.org/PDXBOT/](http://www.portlandrobotics.org/PDXBOT/)

### 12-14 AUVS International Ground Robotics Competition

Oakland University, Rochester, MI  
An autonomous ground vehicle must navigate an outdoor obstacle course within a prescribed amount of time, while staying within a 5 mph speed limit.  
[www.igvc.org/deploy/](http://www.igvc.org/deploy/)

### 19 UK National Micromouse Competition

Technology Innovations Center, Birmingham, London, UK  
Robot mice strive to win the coveted brass cheese.  
[www.tic.ac.uk/micromouse/](http://www.tic.ac.uk/micromouse/)

### 25-27 MATE ROV Competition

University of California (UCSB), Santa Barbara, CA  
Student built ROVs must locate and retrieve objects of varying sizes and shapes.  
[www.marinetech.org/rov\\_competition/](http://www.marinetech.org/rov_competition/)

## 27-7/4 RoboCup Robot Soccer World Cup

Lisbon, Portugal  
This is the big event, with championships for all of the robot soccer leagues, including the Soccer Simulation League, Small-Sized Robots, Mid-Sized Robots, Four Legged (AIBO) Robots, RoboCup Junior, and the Humanoid Robot League. There will also be a Robocup Rescue Robot event. The overall goal is to field a team of robots that can beat the world's best human team by 2050.  
[www.robocup.org](http://www.robocup.org)

## July

### 17 DPRG Table-Top Robot Contest

The Science Place, Dallas, TX  
Mini-robots compete on table top sized courses in line following, sumo, and other events.  
[www.dprg.org/competitions/](http://www.dprg.org/competitions/)

### 19-23 K'Nex K\*bot World Championships

Las Vegas, NV  
Three types of events are included: two-wheel drive autonomous K\*bots, four-wheel drive autonomous K\*bots, and radio controlled Cyber K\*bots.  
[www.livingjungle.com/](http://www.livingjungle.com/)

### 25-29 AAI Mobile Robot Competition

San Jose Convention Center, San Jose, CA  
Robots must navigate the conference center in the "Robot Challenge." They must locate injured humans in "Robot Rescue," and serve humans in "Hors d'oeuvres, Anyone?"  
[www.aaai.org/Conferences/National/](http://www.aaai.org/Conferences/National/)

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# Why

by Larry Barello

# LEGO

# Sensors?

**L**EGO construction kits are amazing toys. With a few standardized parts, you can quickly build fairly rugged structures. Add a computer, motors, and sensors and you can build prototype or final robots. The LEGO Mindstorm kits — with the LEGO RCX Brick computer — add the final pieces needed for building robots: motors, gears, and sensors that easily snap together to rapidly build robots.

The standard LEGO brick, however, has serious limitations. No more than three sensors can be connected at a time (not strictly true, but true if you want full functionality from each sensor) and the programming language has limited access to the capabilities of the internal CPU. I am used to programming in C during assembly and find the expressive power of the native LEGO languages (Robotics Invention System and Robolab) restrictive.

Because of the popularity of the LEGO Mindstorm kits (I suspect many adults purchased them for their kids, but ended up using them, instead; that is my excuse!), there has been considerable activity in extending the basic LEGO system. There are websites detailing how LEGO sensors work and how to create your own special sensors. There are alternate firmware and high level languages available that liberate the creator from the limitations of the stock LEGO RCX controller. For more sophisticated LEGO based robots, more powerful computers, and home-brew sensors, the LEGO Brick and Mindstorm sensors are usually replaced. This combination is popular for teaching robotics at the college level.

In short, it seems that you either use the LEGO RCX brick and try to get around its limitations through alternate software or else you dump all the Mindstorm parts and use custom controllers and sensors with the LEGO parts to build robots. I never saw a third option of using stock LEGO sensors with alternate computers. This didn't seem right,

since the LEGO Mindstorm sensors are rugged, inexpensive, and easily available, in addition to being designed to work with LEGO parts.

Having an extended Mindstorm kit and plenty of extra sensors at home, I became intrigued by the idea of using the stock LEGO parts with my own AVR Robot Control board ([www.barello.net/ARC](http://www.barello.net/ARC)); I wondered if the standard 9 V LEGO sensors would work with the +5 V logic of a simple microcontroller. After performing some quick tests, I found that LEGO sensors work fine with a +5 V system. All you need is an analog input (ADC) and the ability to control whether an I/O port is an input or output.

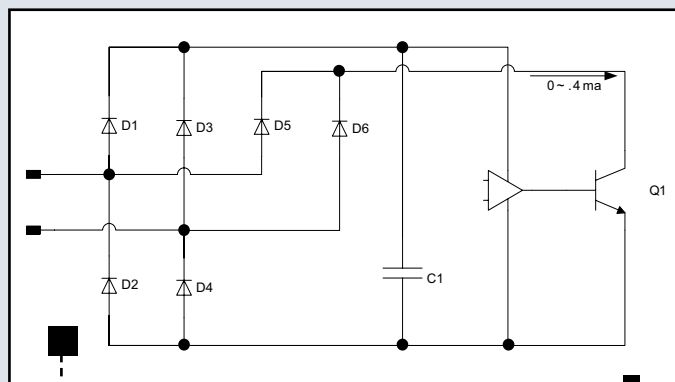
This article describes interfacing LEGO Mindstorm sensors with an Atmel AVR microprocessor ([www.atmel.com](http://www.atmel.com)) using the BASCOM ([www.mcselec.com](http://www.mcselec.com)) basic compiler, but the techniques described should work with PIC and HC11 style microcontrollers using a variety of languages, as long as they support switching an analog I/O port from an output to an input.

## How LEGO Sensors Work

LEGO sensors are very clever



Figure 1



Generalized LEGO sensor schematic

Figure 2

two-wire devices (Figure 1). They are non-polarized so that they can be connected either way and still work. The standard LEGO connector is a 2 x 2 block with connecting plates on either side. The plates are cross-wired so that connecting in any of the four possible orientations will make the circuit work.

Figure 2 illustrates a generalized schematic of the LEGO sensor interface. A voltage applied to the terminals charges capacitor C1 to power to the circuitry. The four diodes — D1 through D4 — form a classic bridge rectifier so that C1 is charged properly, regardless of how the device is connected.

Reading the output signal of a LEGO sensor is also very clever. A 0-400  $\mu$ A current sink — in the form of an NPN transistor — provides the output signal. A current sink will draw a specified amount of current, regardless of the applied voltage. While under power, the output draws a fraction of a milliamp.

When power is removed, the capacitor, C1, continues to power the device and the amount of current being sunk can be measured as voltage across a 10K load resistor.

Note that diodes D5 and D6 are connected to the current sink from each terminal; they route the current to the correct pins, regardless of connector orientation.

Figure 3 shows the Microcontroller interface to

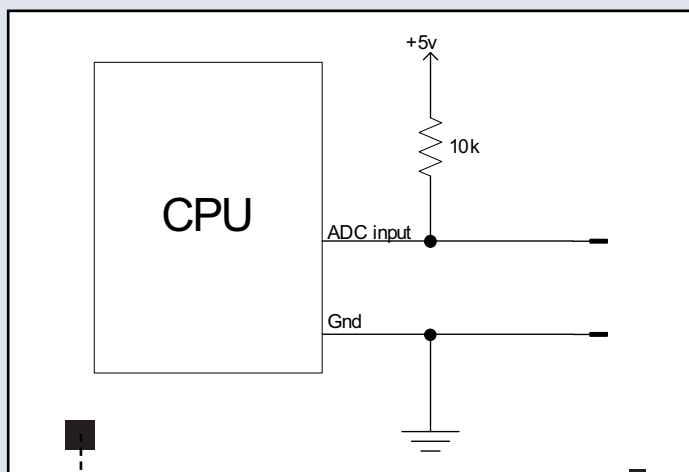
a LEGO sensor.

As the output current varies from 0-400  $\mu$ A, the voltage read by the ADC input will vary from 5 down to 1V. With a 10 bit ADC (typical), the count range will be ~200-1,000. Figure 4 shows a time/voltage graph of powering and reading a LEGO sensor.

After powering the sensor for a minimum of 2-3 ms, the power is removed and the I/O port re-configured as an ADC input. The output of the sensor will settle down within 10  $\mu$ s and the output will be measured. After measuring, the port is re-configured as an output and powers the sensor.

## LEGO Sensors

The LEGO switch sensor is the most



LEGO CPU interface

Figure 3

simple sensor. It is a switch in series with an 800 $\Omega$  resistor. It takes no special software or even an ADC to read.

However, it can be read with the same software as the LEGO light sensor, but will read 100% light when closed.

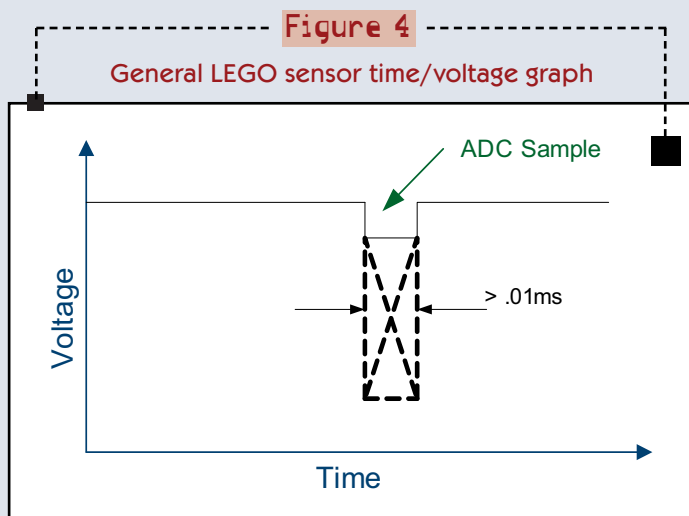
The 800 $\Omega$  resistor solves several problems: when powered, a closed switch won't short the I/O pin to ground, also the sensor can be paralleled across a LEGO light sensor. When the switch closes, the 800 $\Omega$  resistor easily overwhelms the output of the light sensor to bring the output voltage near zero (Figure 5).

The LEGO light sensor is pretty straightforward. It has an output that is the inverse of the light level.

However, the output is restricted to a fairly narrow current range.

All the results obtained here and used in the software were experimentally determined. I found that the LEGO light sensor returned from 600-900 counts from a 10 bit ADC at 5 V from the brightest to darkest light levels. The lower the value, the brighter the light on the sensor (Figure 6).

The third sensor I tried — the LEGO rotation sensor — was a more than a little tricky. The rotation sensor implements a



General LEGO sensor time/voltage graph

Figure 4



## Where to Purchase LEGO Sensors

*PITSCO is the US LEGO educational distributor. You can order over the web or by phone. Their website ([www.pitsco-legodacta.com](http://www.pitsco-legodacta.com)) is a little difficult to navigate, but, if you know the magic part numbers (see the chart to the right), they are easy to find. I included the connecting cables, as well. Order the long ones, cut them in half, and use them to connect the sensors to your controller.*



classic quadrature encoder with four distinct states. The sensor (apparently) has a four-slot encoder disk to give 16 counts per revolution. The rotation sensor communicates this information as four distinct output levels. Figure 7 shows the four levels and their corresponding states, along with how to

decode those states into encoder counts.

Note that, when moving forward, states change in one order and, when in moving in reverse, they change in the opposite order. By examining the previous and current state, the software can determine whether the encoder is moving forward or backward.

The fourth LEGO sensor available is the temperature probe. I did not have a sample of this probe, but the current output versus temperature can be found in the references or experimentally determined.

## Software

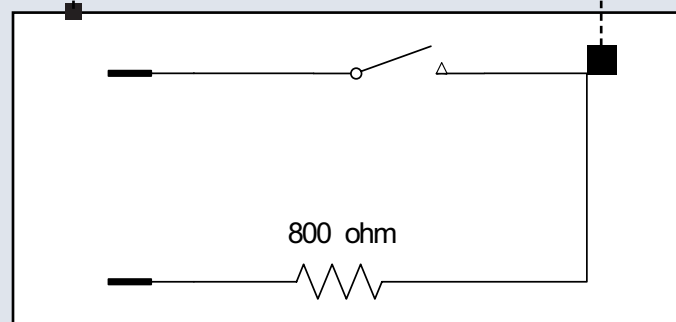
I used an ARC control board and the BASCOM AVR basic compiler for all of my experiments. The AVR CPU has a simplified, flexible I/O structure that facilitates controlling and reading LEGO sensors; it is also very fast, compared to other common eight bit controllers. Using Basic allowed me to generate test code very quickly. BASCOM has structured, basic syntax (if/then/else if/end) and that — combined with the straightforward I/O and interrupt structure of the AVR chip — makes for a thoroughly pleasant programming experience.

The basic logic is to power the device. Then, when reading, remove the power and measure the amount of current the device draws. I minimized the time spent reading and left the device powered when done. This insures that C1 is fully charged the next time the device is read. The LEGO sensors can be read as fast as 300 Hz.

The AVR microprocessor controls the analog I/O port through three registers: Data Direction Register (DDRA), PORT output register (PORTA), and Pin input register (PINA). Each register is a byte wide, corresponding to the eight bits in each I/O port. By setting the DDRA bit to 0, the I/O pin becomes an input. By setting the DDRA bit to 1, the pin becomes an output.

**Figure 5**

LEGO Switch Schematic



**YOU KNOW YOU WANT ONE**

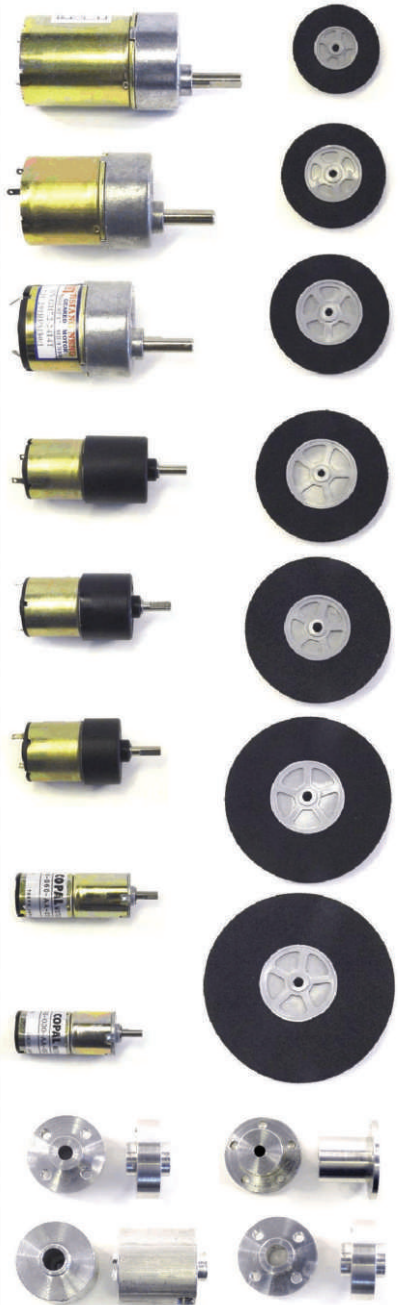
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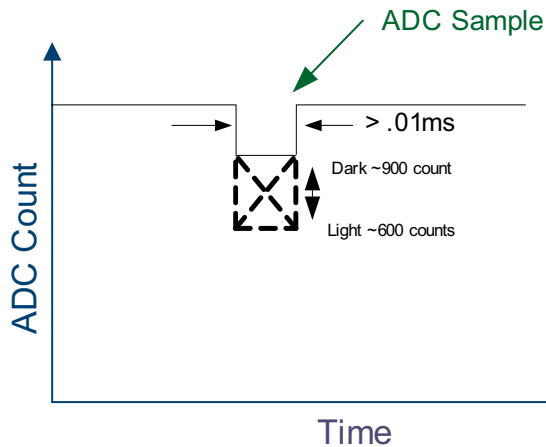
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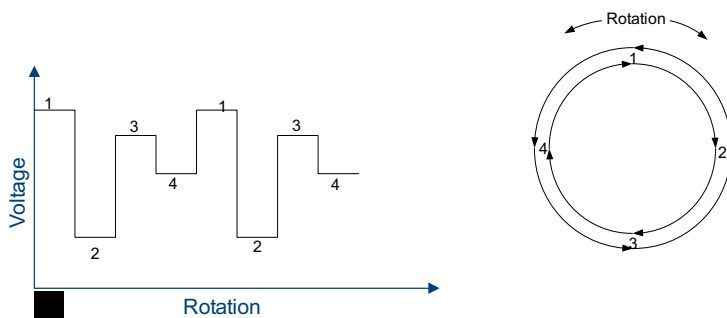
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LEGO Light Sensor Voltage Graph

Figure 6



LEGO Rotation Sensor Voltage Graph

Figure 7

An output writing a 1 to the PORT bit will drive the pin to +5 V and that powers the LEGO sensor. When reading the sensor, both the DDR and PORT bits must be zero. The AVR CPU has an internal pull-up resistor for each I/O pin that activates when DDR = 0 and PORT = 1. Reading the

LEGO sensor requires a 10K load resistor; we don't want to add another, unknown, resistor by enabling the internal pull-up. **SV**

## Resources

AVR Robot Control Board:  
[www.barello.net/ARC](http://www.barello.net/ARC)

AVR Robot Control Board support  
mailing list  
<http://groups.yahoo.com/group/ARC>

BASCOM basic compiler, IDE, simulator,  
and  
programmer  
[www.mcselec.com/download\\_avr.htm](http://www.mcselec.com/download_avr.htm)

LEGO Sensors explained  
<http://personal.pitnet.net/usr/gasper/lego.htm>

| P/N     | Description               | Price   |
|---------|---------------------------|---------|
| W779758 | 9 V Light Sensor          | \$14.99 |
| W979891 | 9 V Angle Sensor          | \$16.99 |
| W779911 | 3x Touch Sensors          | \$11.99 |
| W979889 | 9 V Temp Sensor           | \$27.99 |
| W970041 | 3x Short Connecting Leads | \$10.00 |
| W970654 | Connecting Lead Set       | \$11.99 |



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# ASK MR. ROBOTO

by  
**Pete Miles**

**Q** I'm a radio control (R/C) airplane hobbyist. I've always wanted to build a transmitter and receiver for my R/C airplanes. Do you have any information on these topics? I'm particularly interested in R/C circuitry — custom R/C chips that don't need a lot of external components in addition to plans, ideas, and theories about how R/C transmitters and receivers work.

— **Peter Yang**  
Via Internet

**A** This question really got me thinking about radio control. All of my previous radio controlled robots used the traditional R/C equipment that is typically used to control model airplanes and cars. I use them because the equipment is relatively cheap, easy to interface to a motor controller and a microcontroller, compatible with a wide variety of equipment, and fairly reliable in terms of a communication link.

There are, however, many times when I wished I could get some feedback information from my robots or wanted to send a unique set of commands that really didn't fit well with the standard 1.0 to 2.0 ms pulse width modulation signals that the regular R/C equipment is designed around.

Since designing and building your own R/C transmitters and receivers is a fairly complicated topic (and cannot be covered in a single article), I decided to see how well radio frequency (RF) serial data transmitters and receivers work for

remotely controlling a robot. Since I like using simple, low-cost, plug-and-play, off-the-shelf technology, the 433 MHz RF transmitters and receivers from Parallax ([www.parallax.com](http://www.parallax.com)) looked like the ideal solution. These modules send data to each other using serial communication protocols up to 2400 baud.

Figure 2 shows a schematic for making a simple transmitter using a BASIC Stamp 2 and a couple of joysticks. The receiver circuit also uses a BASIC Stamp 2 on a Parallax SumoBot. I needed to add the 1,000  $\mu$ F capacitor because voltage sag from the batteries when the servo motors changed direction caused the Stamp to reset. The two LEDs are used to provide visual feedback to show if the received data is corrupt or if the signal was lost.

The example programs use a simple, tank style steering to control the robot. In one evening, I was able to convert my autonomous mini-sumo robot into an R/C mini-sumo robot. The transmission range of this device was incredible. I was able to remotely drive this robot around my entire home without losing reliable data communication links.

What makes these devices really nice is that you have full control over how the remote control data is being sent to the robot. All of the control algorithms can be computed on the transmitter side, the receiver side, or split between the two devices. This can simplify a lot of the computational and timing issues.

For example, the transmitter can be used to calculate all of the motor positions, speeds, and directions based on joystick positions and the receiver only has to send the commands to the servos and maintain servo position updates.

One interesting application for these types of devices uses a set of flex sensors to make an exoskeleton suit to remotely control a multi servo arm (such as the Lynx Six arm with five degrees of freedom from Lynxmotion [www.lynxmotion.com](http://www.lynxmotion.com)). Here, the flex sensors could be placed on your robot's shoulder, elbow, wrist, and hand; using some analog-to-digital converters to convert the voltages to servo positions, you can build a remote control without having to use a computer.

**Figure 1. 433 MHz RF Transmitter and Receiver Modules.**



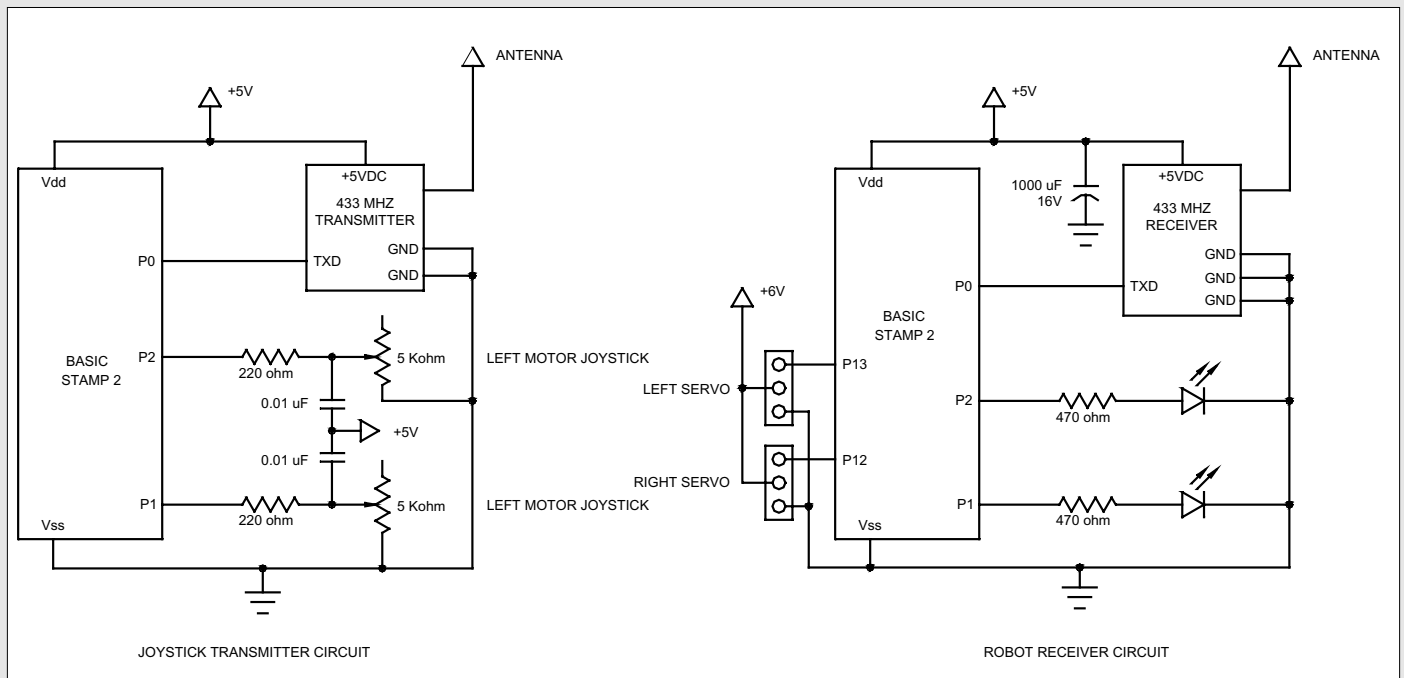


Figure 2. RF Robot Remote Control Circuits.

Though this doesn't directly answer your question regarding building R/C equipment for your airplanes, it should give you some ideas in how to progress towards accomplishing your goal.

One thing to keep in mind is that you need to make sure that the type of data communication link you use is 100% reliable or your plane might fall out of the air and hurt someone. 900 MHz systems with data encryption systems would be a better choice with higher transmission ranges and rates (greater than 2400 baud).

The following two programs show how the transmitter and receiver programs work for driving a robot using tank style steering via serial RF communications.

```
{ $STAMP BS2 }
{ $PBASIC 2.5 }

' Transmitter Demo
' RC Time constants based on using a 0.01uF capacitor,
' 5 Kohm potentiometer, and a 220 ohm resistor between
' the Stamps I/O pin and the RC circuit.
' Drive Command XY

' X = Left Motor, 0-Reverse, 1-Stop, 2-Forward
' Y = Right Motor, 0-Reverse, 1-Stop, 2-Forward
' Example Drive Command 02 Left Motor Reverse,
' Right Motor Forward

' The program works by reading in the potentiometer
' position by using the RC time function. The joysticks
' represent forward stop, and reverse commands that are
' encoded to values of 2,1,0, respectively. Then both
' command positions are encoded into a single byte number
' where the tens digit represents the left motor command,
' and the ones digit represents the right motor command.
' The drive control is using a tank style steering. The
' transmitter sends two bytes of data. The first byte has
```

' a value of 255, and the second byte has the command 'value. The 255 number is a sync byte to tell the ' receiver to start looking for the commanded value.

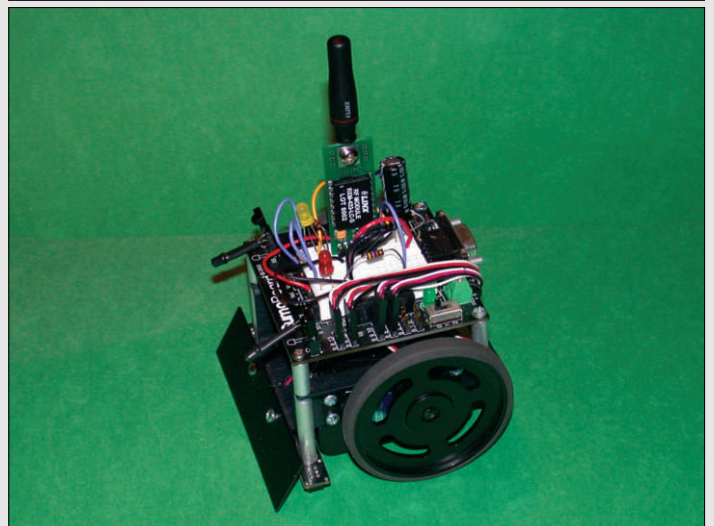
' Declarations

```
TxPin      CON 0      ' Transmitter Pin
Baud       CON 16780  ' 2400 Baud, 8 Bits, No Parity,
                  ' 1 Stop Bit, Inverted
L_Motor    VAR Byte   ' Left Motor Command
R_Motor    VAR Byte   ' Right Motor Command
Command    VAR Byte   ' Drive Command
```

' Initialize  
LOW TxPin

Main:  
HIGH 1

Figure 3. RF remote controlled robot.





```

HIGH 2
RCTIME 1,1,L_Motor
RCTIME 2,1,R_Motor

command = 11

IF L_Motor < 10 THEN      'Left Motor Reverse
  Command = Command - 10
ENDIF
IF L_Motor > 20 THEN      'Left Motor Forward
  Command = Command + 10
ENDIF
IF R_Motor < 10 THEN      'Right Motor Reverse
  Command = Command - 1
ENDIF
IF R_Motor > 20 THEN      'Right Motor Forward
  Command = Command + 1
ENDIF

'DEBUG HOME, DEC2 command, " ", DEC3 L_Motor, " ",
DEC3 R_Motor
SEROUT TxPin, Baud, [255, command]
PAUSE 10
GOTO Main

'{$STAMP BS2}
'{$PBASIC 2.5}

'Receiver Demo
'This program receives a 2 byte serial command. The
'first byte is the sync byte (255), and the second byte
'is the actual movement commanded byte. If the first
'byte received is not 255 then the program ignores the
'second byte of data, and lights a bad data LED. After
'it receives the commanded data, it decompiles it into
'the two motor direction commands, and then checks to
'see if the values are within the specified range.
'If it is not, then it will light the bad data LED. With
'good data, the servo motors will be commanded to move
'Forward, Stop, or Reverse, depending on the commanded
'values. Then the program cycle repeats. The Serin
'command uses a timeout in the event that no data is
'received within 100 ms, it would light the data timeout
'LED. This is here in the advent of alerting you that no
'data is being received.

'pin13 left servo motor  1000 fwd  500 rev
'pin12 right servo motor  500 fwd  1000 rev

```

```

'pin0 Receiver input
'pin1 bad data line
'pin2 data time out

'Declarations

RxPin      CON 0
Baud       CON 16780 '2400 Baud, 8 Bits, No Parity,
              ' 1 Stop Bit, Inverted

Command    VAR Word  'Input motion command
Sync       VAR Word  'Sync Byte
LStop      VAR Word  'Left Servo Motor Stop value
RStop      VAR Word  'Right Servo Motor Stop value
L_Motor    VAR Word  'Left motor command from Tx
R_Motor    VAR Word  'Right motor command from Tx
Left_Motor VAR Word  'Left motor direction command
Right_Motor VAR Word  'Right motor direction command
Flag       VAR Byte  '1=error, 0=no error

'Initialize
INPUT RxPin
LStop = 755      'Left servo motor stop pulse position
RStop = 755      'Right servo motor stop pulse position
Flag = 0

Main:
  IF flag = 1 THEN  'Bad Data
    HIGH 1
  ELSE
    LOW 1
  ENDIF

  'Get data
  SERIN RxPin, Baud, 100, TimeOut, [Sync, Command]
  IF Sync <> 255 THEN  'Data out of Sync
    Flag = 1
    GOTO main
  ENDIF
  L_Motor = Command/10
  R_Motor = Command//10
  IF L_Motor > 2 THEN  'Data out of Range
    Flag = 1
    GOTO main
  ENDIF
  IF R_Motor > 2 THEN  'Data out of Range
    Flag = 1
    GOTO main
  ENDIF
  Flag = 0
  LOW 2
  'DEBUG DEC3 Sync, " ", DEC3 Command, CR

  LOOKUP L_Motor, [500,LStop,1000],Left_Motor
  LOOKUP R_Motor, [1000,RStop,500],Right_Motor

  PULSOUT 13, Left_Motor
  PULSOUT 12, Right_Motor

```

```

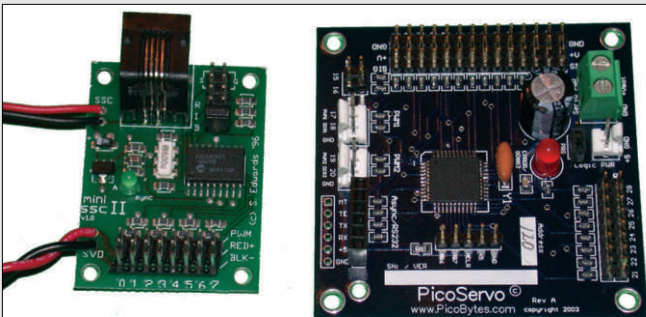
GOTO Main

TimeOut:  'No data received, Serin cmd timed out
  Flag = 1
  HIGH 2
  GOTO Main

```

**Q** I am very interested in robotics, although I don't know how to program. Are there some fairly inexpensive BASIC Stamp kits that would teach me

**Figure 4.** Mini SSC II (left) and the PicoServo (right) servo controllers.



the language?

I was wondering if this would be a good idea. If not, what controller should I use? Also, if I did learn about the BASIC Stamp, could I use it on Peg-Leg and the mini-sumo? If you have the time to answer, I'd appreciate it.

— Colin Ware  
Via Internet

**A**. Learning how to use the BASIC Stamps from Parallax ([www.parallax.com](http://www.parallax.com)) is probably one of the best places to get started in robotics. Their documentation is designed to teach people how to program and put together basic electronic circuits without prior knowledge. They have many step-by-step examples that show you everything you need to know to get started in the world of robotics and there is a tremendous amount of support on the Internet for BASIC Stamps.

A fairly inexpensive kit to get started with is Parallax's BoeBot kit. It is flexible and has a set of experiments for learning new behaviors and capabilities with the robot. Parallax also sells a BASIC Stamp version of a mini-sumo called the SumoBot.

So, to answer your other question, yes, the BASIC Stamps can be used on a mini-sumo. In fact, all of my sumo robots use them and, yes, it works with the Peg-Leg.

**Q**. I want to build a cool-looking robot that appears to be playing the drums. What if I were to pre-record a snare drum and play back the sound to trigger an arm holding a drum stick? That's the basic idea.

It's kind of like the light that blinks on a tape recorder when there is sound. Instead of triggering a blinking light, we would trigger a swinging arm. Since the drum track is a recording, the robot doesn't have to actually make a sound when it hits the snare drum; it just has to look like it's hitting the snare drum in time.

After I build this "rockabilly" robot drummer, I will build the rockabilly robot bass player, which will be a bit more complicated because the movement of one arm will be determined by pitch (up and down the neck). How do I get started? Thanks.

— Eddie Vincent  
Via Internet

**A**. This is actually not very hard to do. In fact, there is an entire robotics field that does this type of work — animatronics. What you will need is a device called a servo controller, which is used to control the motion of several model airplane radio control servos.

These servos will be used to move the drum sticks of your drummer. One configuration could have one servo each for the shoulder, elbow, and hand for moving the drumsticks. The more servos you use, the more realistic the body motion that can be simulated.

A simple set-up would use an eight servo controller

called the MiniSSC II from Scott Edwards Electronics, Inc. ([www.seetron.com](http://www.seetron.com)). A computer or microcontroller is used to send serial data to the controller, telling it which servo to move and how much it should move. The main microcontroller or computer is used for synchronizing the servo movements with the music.

If you want to use a personal computer, there is software available that will play the music and command the servos to move together to make a very realistic looking drummer. Robo-Ware, available at Reynolds Electronics ([www.rentron.com](http://www.rentron.com)), has a very nice and affordable software package that does this.

At the Scott Edwards website, there are links to several other companies with software that works with the MiniSSC.

If you don't have room for a computer, then a microcontroller can be used. Just about any microcontroller can be programmed to control the MiniSSCs — or even several of them at the same time. The only difference is that you have to program the timing delays for the servo controller yourself.

Table 1 shows a list of some of the more advanced servo controllers that have their own memory and programming environments, so that a single device can be programmed to run all of the servos.

For a complete, self-contained control system, take a look at the Quadravox QV430P or the QV502 systems at [www.tetraphon.com](http://www.tetraphon.com) for playing the robot sounds, instead of using a computer's sound card.

These sound systems can be programmed with WAV or MP3 sound files and can be accessed with a microcontroller to precisely synchronize the sound output with the robot's arm motions.

Once you have the robot drummer rocking along, you can then put together the robot bass player using the same technology, then add the lead singer. **SV**

| Model                     | Number of Servos | Programmable | Company                                                                                 |
|---------------------------|------------------|--------------|-----------------------------------------------------------------------------------------|
| MiniSSC II                | 8                | No           | Scott Edwards Electronics, Inc.<br><a href="http://www.seetron.com">www.seetron.com</a> |
| SZ203B                    | 8                | Yes          | Pontech<br><a href="http://www.pontech.com">www.pontech.com</a>                         |
| ASC16                     | 16               | Yes          | Medonis Engineering<br><a href="http://www.medonis.com">www.medonis.com</a>             |
| Parallax Servo Controller | 16               | Yes, limited | Parallax, Inc.<br><a href="http://www.parallax.com">www.parallax.com</a>                |
| PicoServo                 | 20               | Yes, limited | PicoBytes, Inc.<br><a href="http://www.picobytes.com">www.picobytes.com</a>             |
| ServoPod                  | 25               | Yes          | New Micros, Inc.<br><a href="http://www.newmicros.com">www.newmicros.com</a>            |

Table 1. Various Servo Controller Manufacturers.





# TETSUJIN TECH

## PART 1: LINEAR ACTUATORS

by Jared Zammuto

Selecting the right electro-mechanical linear actuator for your Tetsujin exoskeleton seems simple — at first. It must be cost-effective, simple to operate, and easy to install into your framework. You may quickly rule out hydraulics because of the cost and the potential for leaks. For our example, assume you are running a 12 volt DC power system and a mechanical geometry that — when lifting the bar — needs about 450 lbs of force and travels 10-11 inches for a full cycle.

Is it as simple as opening a catalog and matching up the numbers? Well, sometimes it is, but more investigation is usually necessary to make a sound decision.

Is the load really what you think it is? Compression, tension, and electro-mechanical linear actuator forces that are in line with the load vertically are easily identified as the “weight” of the load. If the application requires that the load be moved horizontally, friction must be accounted for. Moving the load horizontally may require less actuator force than moving it vertically would, but the forces required to accelerate the load may be more than anticipated.

In the case of our Tetsujin exoskeleton, the application Requires the load to be moved in a hinged fashion. Not

only is the actuator applied at an angle, but the angle changes as the actuator extends and retracts.

When applied at an angle to the load, it requires more force than it would if it was directly in-line. In these cases, it is recommended that a drawing or sketch be made to identify exactly how the actuator will be applied. This sketch can be used to identify the dynamics of the load.

In addition to the operating information, you must know the duty-cycle when you apply an electro-mechanical linear actuator. The duty-cycle is the actuator’s on-time, divided by the sum of the off-time and on-time. This is very important because most actuators are limited to a 25% duty-cycle at a full rated load. While it is true that the actuator can operate outside of this specification, applications must be thoroughly evaluated to ensure the proper life and operation of the actuator.

Any time you need to operate an actuator outside of the 25% duty-cycle specification, it is recommended that you create a load/cycle time chart and carefully evaluate it.

In our case, we find that the actuator may operate four to five times throughout the day; it takes less than a minute to complete the cycle and it is fully loaded for only three seconds. There is plenty of off-time, allowing any heat to dissipate before another cycle is required.

Properly mounting a linear actuator is critical. They cannot tolerate side loads, which will

cause it to bind, and possibly buckle. The load can not be offset or cantilevered from the center-line of the actuator ram. The mounts must also be able to restrain the torque developed while operating the actuator.

As a general rule, the mounting must be able to withstand 125 in-lbs of torque. If the standard clevis-style mounting is utilized, the clevis pin must be supported on both sides of the actuator’s mono-clevis. Special mounts must be evaluated to ensure the proper operation and long life of the actuator.

There are a few basic types of screw and drive nut combinations. Bronze drive-nuts or plastic drive-nut screw combinations are inherently self-locking. The load, traditionally, will not drift or move after power is removed from the actuator.

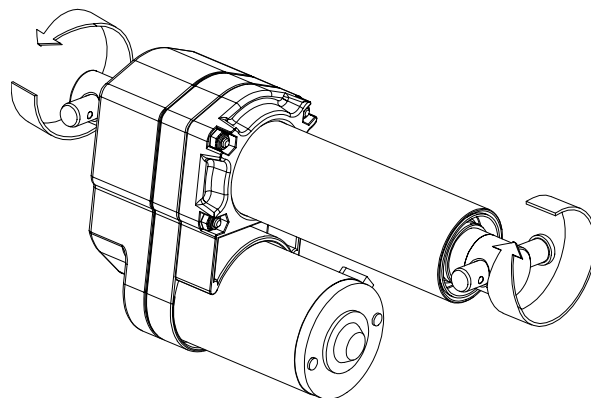
A ball bearing nut and screw combination is also very efficient; this is referred to as a ball screw type of device. It only loses about 10% of its input torque to friction when transmitting rotational movement to linear movement.

Thus, when power is removed from an actuator that utilizes a ball screw, the load will move. This is known as back-drive. A holding brake must be utilized to prevent back-drive. Bear Linear provides a holding brake for its entire line of ball screw models.

In some cases, a bronze drive-nut or plastic drive-nut screw combination may be subjected to intense vibrations when loaded. This can allow their



Cutaway drawing of a K2 series linear actuator with a recirculating ball nut.



The mounting points must be able to tolerate a 125 in-lb torque during operation.

self-locking features to be negated. A holding brake can be provided in these cases, as well.

The safety of the operator and protection of your equipment are of utmost importance. Power connections are sometimes overlooked. The length of the wire and its current capacity must be evaluated. Too long of a wire run or the wrong wire size can cause significant voltage drops. Too much voltage drop can cause poor performance in the electro-mechanical linear actuator. Even worse, exceeding the amperage capacity of a wire could cause a fire.

An actuator is protected in many ways. Motor thermal-breakers protect the motor from overheating. A clutch protects the unit at the ends of the stroke or from a mid-stroke overload condition. The clutch can also be used to limit the travel. If the actuator is loaded over capacity, the clutch will slip, creating an audible clicking sound. By hitting fixed end stops, the operator can hear the clutch ratchet, which indicates that it is time to remove power from the actuator.

An in-line fuse or circuit breaker should be used in all applications. An actuator can be controlled manually with a switch or a special purpose controller. Adding internal limits and feedback, along with a special purpose controller, can achieve low-cost, servo-like performance.

You can have accurate stroke positioning and multiple cycle features, creating a motion control system on a highly specialized machine. A special purpose controller can also incorporate additional safety features that are specialized to your application.

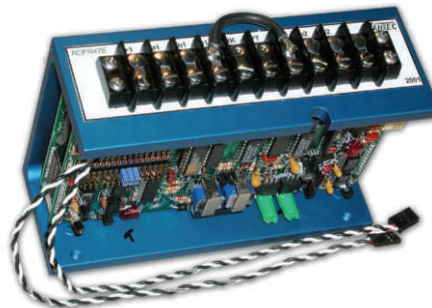
The environment that a linear actuator will be subjected to can significantly affect the actuator's performance and life. Precautions must be taken to ensure that the operating temperature never exceeds 150° F. Premature motor failure is eminent at 180° F. Operating an actuator below -15° F is not recommended, either.

It is important to select an actuator that resists internal corrosion. If the application is outside, where it will be exposed to the elements, it must be weather tight. Power connections must be protected from moisture. High pressure wash-downs and exposure to corrosives must be considered, as well. Ingesting dirt or abrasive matter is an actuator's worst enemy. Overlooking something here could greatly reduce the life of the actuator.

I've covered the most important factors in selecting the correct linear actuator for your project. Having a good understanding of the factors involved helps you obtain the best suited — and most economical — electro-mechanical linear actuator for your application. **SV**

Jared Zammuto is an applications engineer with Bear Linear, leading manufacturers and assemblers of electro-mechanical motion control systems. To contact Bear Linear, call (815) 547-1106 or visit them on the web at [www.bearlinear.com](http://www.bearlinear.com)

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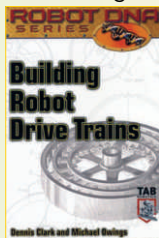
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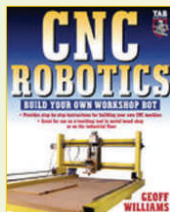
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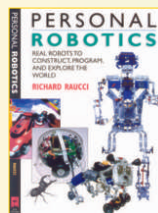
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by Doug Williams

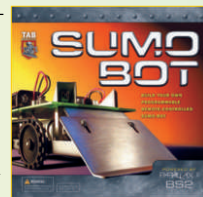
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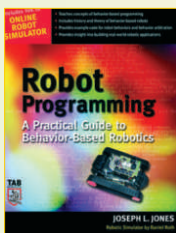
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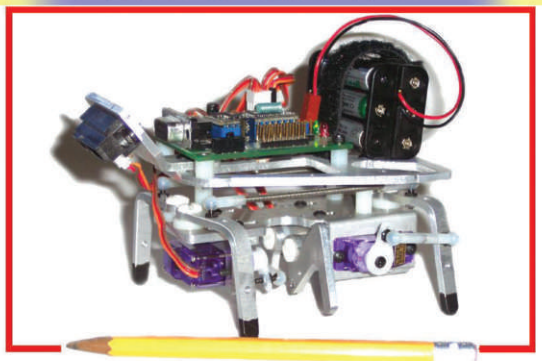
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by Hobart R. Everett

In *Sensors for Mobile Robots*, the author compiles everything a student or experienced developmental engineer needs to know about the supporting technologies associated with the rapidly evolving field of robotics. **\$69.00**



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# CUTTING EDGE ROBOTICS

## Part 4 — The Cutting Edge Robot Controller

These past three months, we have been very busy building and modifying the Cutting Edge (C. E.) Robot. As we get deeper into the project, we must learn new facts about robotics. Each component is a vital part and can become a problem if not fully understood. To name just a few possible problem regions, we have the sensors, motors, motor drivers, and — foremost in my mind — the controller. I would like to take this opportunity to clarify some points before we continue with more robotic expansions.

### Good News, Everyone

Last month's addition to our robotic arsenal was a pair of crank powered peg-legs. I know there are some of you out there wondering what you can do with a walking robot. Well, the ECRG (Eastern Canada Robot Games) is adding a new event, based on the walker. It is within the competition's rules that the good news resides. The crank and cam powered walking robots will be allowed to compete and will also be eligible for the top prizes.

Robots will be required to traverse a variety of terrains within a simple maze and the best time wins. The rules state that a handicapping system will be implemented in order to be fair to the various robots. For example, leg and stride length will be plugged into a formula in order to extract the true speed and ability. The full set of rules can be found on the official ECRG website ([www.robotgames.ca](http://www.robotgames.ca)).

### Basically New

As a reader of *SERVO* and *Nuts & Volts*, you are most certainly familiar with the BASIC Stamp. The Stamp has been the mainstay of hobby engineering for quite some time. It has been an old, reliable friend and has allowed us to quickly build very complex and otherwise impossible devices in a very short time. For those who are not too keen on learning about yet another processor, I have designed a very simple controller. It is a carrier board for a Stamp-like module, rather than just another processor (Figure 1).

### Enter the BX-24

As good and reliable as the BASIC Stamp may be, the new, compatible BX-24 stamp-module from NetMedia has surpassed the competition (Figure 2). The

by  
**John Myszkowski**

BX-24 is faster and has more program memory and I/O. It includes an eight input hardware ADC (Analog-to-Digital Converter) and is capable of multi-tasking. Those are the very features needed by our robot in its present and future forms.

The CERc (Cutting Edge Robot controller), seen in Figure 3, is able to utilize any 24 pin device, but is especially useful with the BX-24.

Until now, we didn't have the need to use the ADC, but, already, some of you have asked about using the analog versions of the Sharp GP2D sensors. With the BX-24, you will be able to use these sensors with only a change in software.

The most important feature of the BX-24 is its ability to control eight servos *and* run the rest of the robot's software simultaneously. We will need that ability to control all the servos of the ARM (a future "Cutting Edge" project).

Those of you that have the venerable, old 24 pin BASIC Stamp (BS2 and better), it will do the job for now. For new hobbyists who haven't invested in a microcontroller yet, I suggest the BX-24, as it provides additional room for future expansion – and experimentation!

The PCB layout is available in PDF format from the *SERVO* FTP site for printing your own board. The CERc circuit board will be made available through [www.cuttingedgeprojects.com](http://www.cuttingedgeprojects.com). Details are in the sidebar. I have included the full schematic diagram for those who wish to hand wire the circuit (Figure 4).

As long as we are on the subject of the controller, let's check out some of its features. The module is at the heart of our board and all of the I/O is transferred to the handy connectors. The nine pin, female, "D" connector handles the necessary programming traffic (Figure 5).

The pins in the front of the board

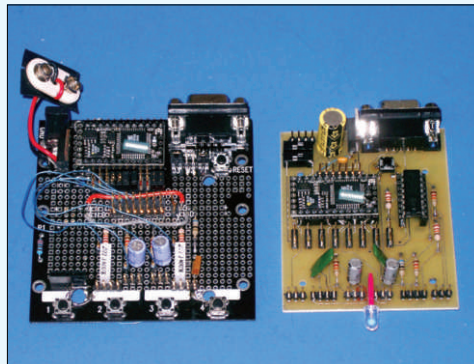


Figure 1. Finished PCB on the right and the hand wired circuit on the left.



Figure 2. Basic-X24 chip from NetMedia.

are for connecting the sensors and motors. The two, 3-pin connectors in the center are for the Sharp object sensors. The two, 4-pin connectors on either side are for line sensors and the outside two are for the two DC motors.

If you decide to use recycled servo electronics with your DC motors, then you can use the servo control connectors, as described in the following section (Figure 6). The eight, 3-pin connectors beside the BX-24 are for directly controlling standard R/C servos. The BX-24 can drive eight servo motors. These connectors can also be used as general purpose I/O pins. The three pins are very handy; they include the ground, power, and I/O pin.

The H-bridge is controlled via pins 17 through 20. These pins are also available through the 6-pin connector for other uses, if they are not used for controlling the L293 chip. More I/O pins are available through the spare connector on the BX-24 module.

The extra I/O connector on the BX-24 includes a regulated 5 volts and ground, so a low power, self-

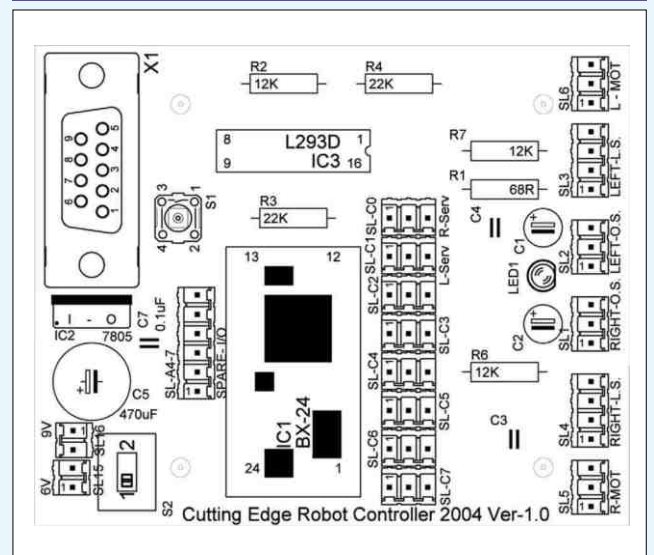
contained circuit can easily be added to it.

The CERc board contains a voltage regulator circuit which is used for the sensors and an L293 H-bridge chip. Consistency of sensor readings varies with supply voltage; the voltage regulator keeps the outputs more stable. The addition of the L293 chip adds flexibility to the controller and allows you to choose the type of motors used in your robot. The L293 is more than sufficient for your small machine.

## Servo Electronics

Those of you who are planning to

Figure 3. CERc parts layout, showing where the BX-24 chip is located.





## A Multi Function Robot — Part 4 <<<

build an R/C battle robot will be interested in this bit of knowledge. The Mark-III controller, in its native mode, is designed to control modified R/C servos, not DC motors.

Thanks to the reclaimed servo electronics, you can now easily control regular DC motors (Figure 7) with a simple robot controller (like the MK-III or Parallax BS2) or a standard hobby R/C rig (transmitter and receiver combo).

I have a bunch of old R/C servos that have stripped or broken gears (Figure 8) and I suspect that many individuals active in the robotics hobby do, too. If the servo electronics are in

good working order, they can still be reclaimed for use in our project. The tiny motor controller accepts the R/C servo control signal and converts it into true PWM to drive any small DC motor.

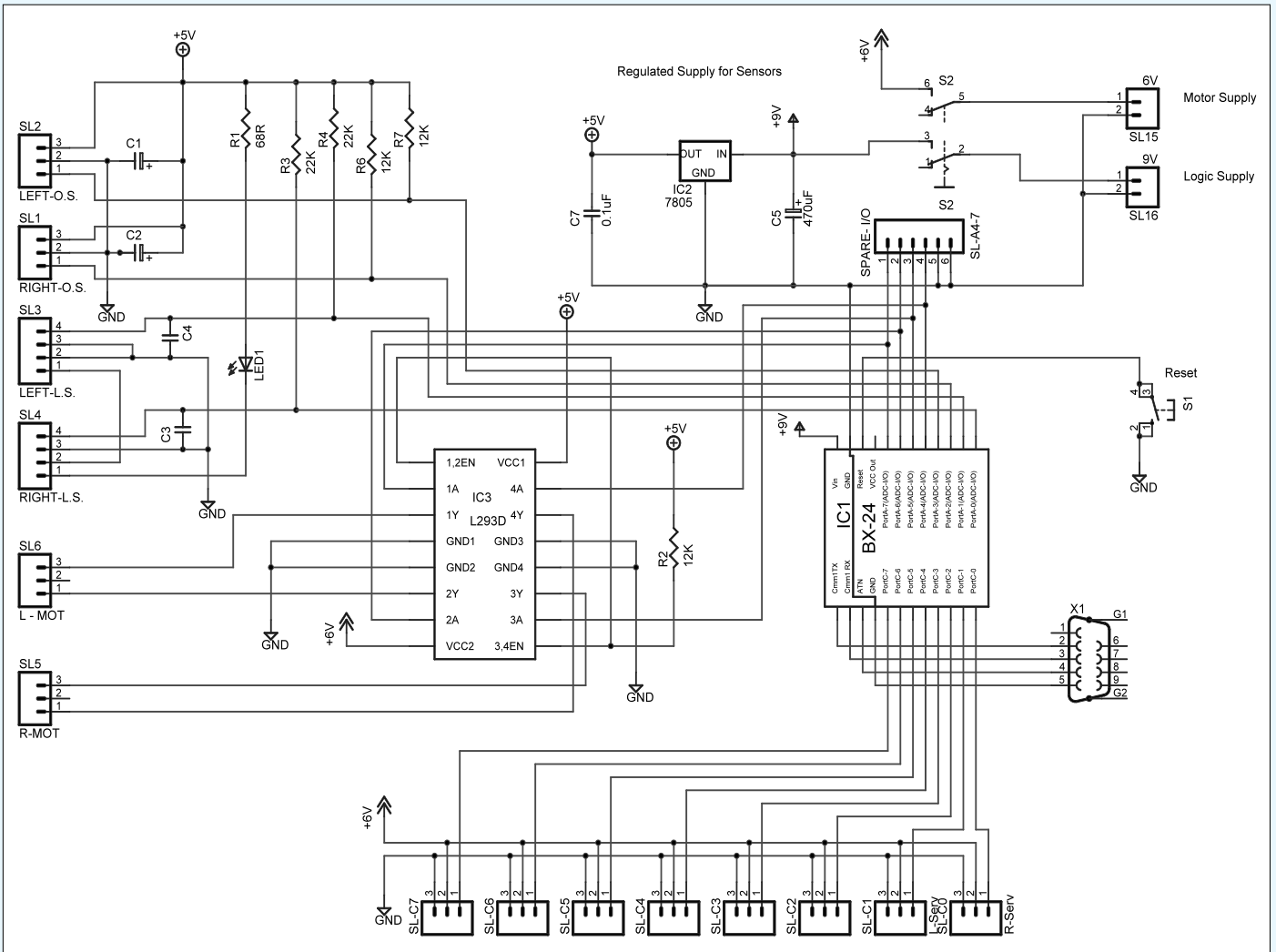
I stripped all of the electronics from the bad servos first. The tiny motor controller can be easily separated from the tiny motor with the hot tip of a soldering iron. Heat the connection until the solder melts.

Now, just bend the motor lead away from the circuit board. A desoldering tool, such as a solder sucker or an older wick can be very handy in this case (Figure 9).

The position feedback is achieved through a small, 5K potentiometer. You need to replace the pot with two 2.7K resistors. This will position the feedback signal roughly in the center. The tiny controller will now think the pot is in the center resting position (Figure 10).

To adjust the motor speed, you need to send an R/C servo compatible signal to the controller. A 1.5 ms pulse or "resting" position will make the motor stop. The width of the R/C servo pulse ranges from about 1.0 ms to about 2.0 ms. A pulse longer than 1.5 ms will move the motor forward and a shorter pulse will move it in reverse.

Figure 4. CER controller schematic, utilizing the BX24.



Any deviation from that 1.5 ms position will make the motor rotate forward or in reverse. A small deviation from the resting position will move the motor slowly and a larger deviation will make the motor rotate faster.

## L293

Not everyone has a pile of broken servos ready to be recycled and it is probably not a good idea to recycle new or still working R/C servos in this manner.

A different way to control the motors is with direct PWM signals and an H-bridge power control circuit. The CERc uses a special chip – the L293 – which is designed for driving DC motors. This chip accepts the speed signal (ON/OFF or PWM) on one input and the direction signal on a second input. The L293 will drive two DC motors with up to 1 amp of current each (Figure 11).

Most controllers are too slow to implement full, PWM speed control of DC motors in BASIC. A simple, yet effective, solution is to control the motors via plain ON/OFF and DIRECTION lines. Even without variable speed control, this solution is quite effective and has been used in many robot designs.

The BX-24 has built-in PWM hardware, which simplifies DC motor control; you only need to send one command and the PWM hardware

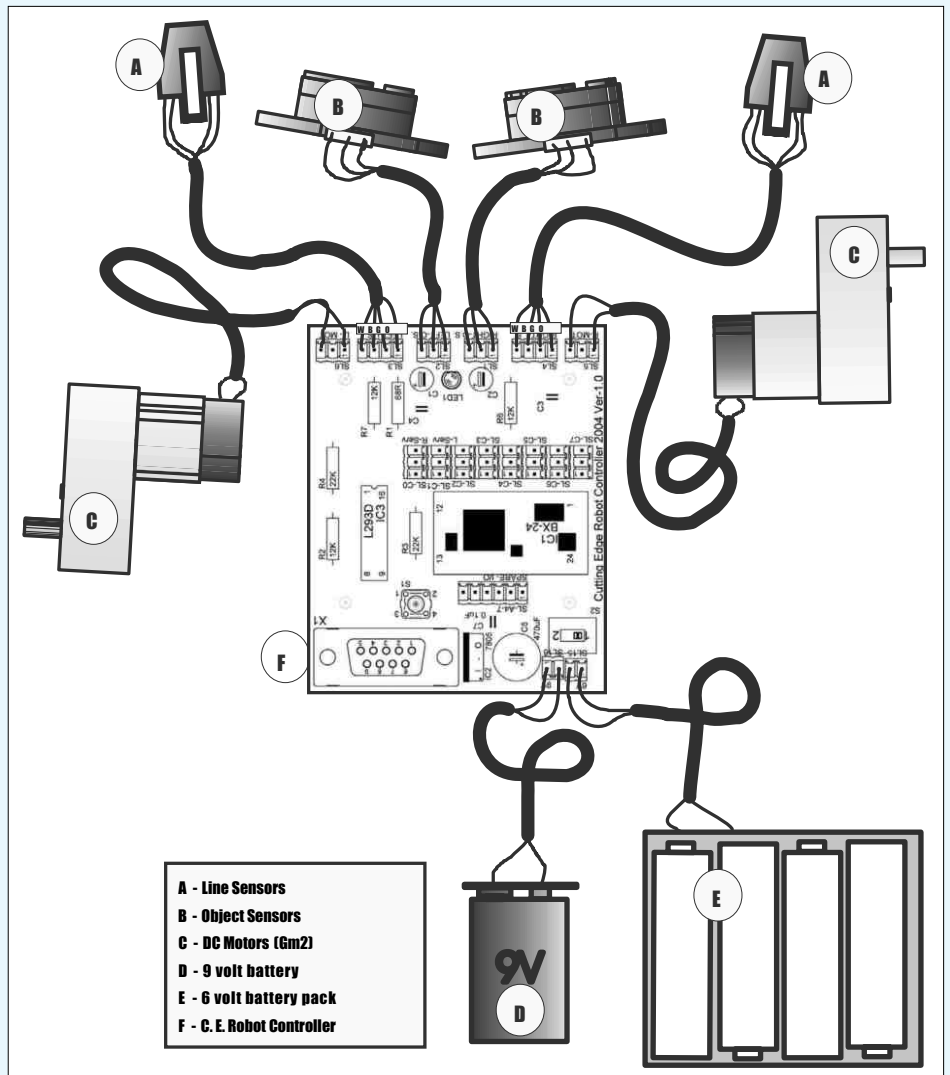


Figure 5. Hookup diagram of the C. E. Robot, showing the wiring details.

takes over from there. Your programs can then take care of other tasks,

such as looking at sensors and making decisions. PWM control

Figure 6. Reclaimed R/C servo electronics board, attached to a larger DC motor.

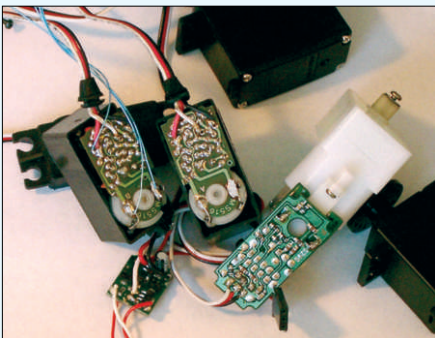


Figure 7. By using the reclaimed R/C servo electronics, it is possible to use larger motors with a regular R/C receiver for larger robots.

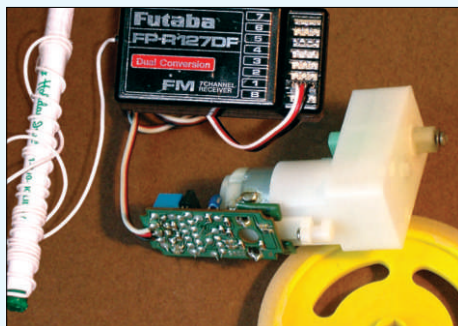
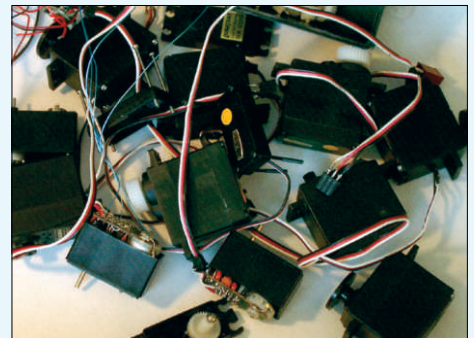


Figure 8. A collection of old or broken servos – a robotic hobbyist's dream.

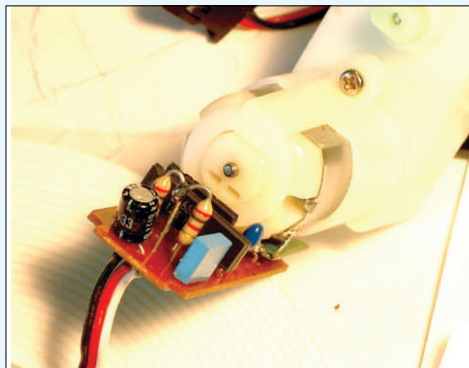




## A Multi Function Robot — Part 4 <<<



**Figure 9.** Removing the control electronics from an old R/C servo.



**Figure 10.** The potentiometer is replaced with two 2.7K resistors.

controllers have plenty of spare I/O pins.

### Sensors

For a minimal sumo robot, you will need at least two sensors. One sensor is for detecting the white line, so your robot doesn't just drive off the edge of the sumo ring; the second is for detecting the enemy. Our C. E. Robot controller will drive two line sensors and two object (enemy) sensors to double the chances of detection and winning

needs two output lines for each | motor, instead of just one, but Stamp | (Figure 5). Left/right object sensors or

line sensors tell us the direction in which to send the robot. You can add more sensors to the rear or sides of your C. E. Robot to help detect enemy robots at all times and enable immediate reactions to any perceived threat.

### ARM4 — CERC Assembly

There is really very little to do in the way of assembly. The pin headers fit exactly as indicated on the PCB or the parts layout; the same goes for the remaining components. Please pay attention to the component polarity in electrolytic capacitors, LEDs, IC sockets, and the voltage regulator. Be especially careful with the power hookup; reversing the battery polarity will most likely destroy the ICs.

#### Testing

Before assembly, take the board in your hand and hold it against a strong light. Check for any possible shorts or broken traces. Fix them, if necessary.

Do not insert the BASIC chip or the L293 chip yet.

After you fully assemble the PCB, you will need to check the voltages at the IC sockets.

Plug in the batteries at this point and turn on the power switch.

Use the schematics to determine where the GND and various voltages (5, 6, and 9 volts) should be.

When all of this checks out, turn off the power, connect the sensors, and turn the power back on.

The LED should now be on.

If the LED is not on, then it or one of the sensors is plugged in

backward. Fix it and try again.

Turn off the power.

Now, plug in the BASIC chip and the L293 motor driver.

Connect the board to the PC with a straight through serial cable (obtained from NetMedia) and load your program.

Check with NetMedia for programming instructions.

#### Problems

In case of problems, check all solder connections. There were plenty of soldering articles in the recent "Cutting Edge" projects in *SERVO* that explained the procedure and possible problems.

To cut to the chase, the prime culprit has always been the cold solder or dry joint, but, if in doubt, look up the old articles.

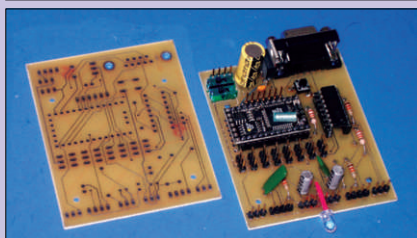
Re-solder any suspicious looking joints.

Solder will create shorts if it is splashed across two traces or pads. Reheat and remove all solder splashes.

A strong light is essential for locating problems on the PCB. A magnifier is also very useful in soldering.

Components in wrong locations or with reversed polarity (if polarized) should be removed and replaced. It is easier to cut out the part and replace it with a fresh one, if available.

The bare CERC PC board and the populated controller



## Components

|                                                                                                                                                                                                                                                                                                            |                                                                                                                                                                                                                                                                                |                                                                                                                                                                                                                                                                                 |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>1</b> — PCB (or perforated board for hand wiring)<br><b>1</b> — 7805 voltage regulator for the sensors<br><b>1</b> — 220-1,000 $\mu$ F (470 $\mu$ F will do fine) capacitor for the power supply<br><b>2</b> — 10 $\mu$ F cap for the two Sharp sensors<br><b>3</b> — 0.01-0.1 $\mu$ F bypass capacitor | <b>2</b> — SPST slide switch Digi-Key #EG1903-ND<br><b>1</b> — Reset switch PB-microswitch, Jameco #153251<br><b>1</b> — LED for voltage drop and indicating the state of the line sensors<br><b>1</b> — 56K resistor for the line sensors<br><b>2</b> — 12K pull-up resistors | <b>2</b> — 22K pull-up resistors<br><b>1</b> — 1 x 7 pin header<br><b>1</b> — 1 x 4 pin header<br><b>12</b> — 1 x 3 pin header<br><b>2</b> — 1 x 4 pin header<br><b>1</b> — 16 pin IC socket<br><b>1</b> — 24 pin IC socket<br><b>1</b> — DB9-F 9 pin, female, serial connector |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

## "simpleSumo" Program

Those of you who are familiar with programming can skip my explanations and move on to downloading the program to the robot.

For the rest of you, I will try to keep it simple.

### Declarations

Declaring constants and variables is a way of getting the CPU ready to run the program. Depending on what is needed by the program, we have to "declare" the constants and variables as integers, floating points, text strings, etc. Constants are the program variables that do not change after the program starts.

The CPU has to be told which of the I/O pins is going to be used and for what purpose. Some lines are set as digital outputs and some as digital inputs. Others can be made into analog inputs. The "simpleSumo-B24" program is written for the GP2D15 sensors, which have only digital outputs. You can modify the program for use with analog sensors, but I want to keep this simple.

### Main Program

The main body of the "simpleSumo" software is made up of the "main" program, its "subroutines," and "tasks."

Our "main" program first calls the task "sleep" and passes the number "5.0" to it. This results in the CPU going to sleep for five seconds. This delay is in accordance with the official Sumo Regulations: "all robots must wait five seconds after the word 'GO.'"

### Tasks

The next task is called with the "CallTask" command, which starts the task running in the background.

This task is for controlling the robot's motors. It is called the "Drive\_System\_Task" and reads a number of variables to use in adjusting the direction and speed of our motors.

This motor control task is called only once and runs forever in the background — or until the CPU is reset. It is only possible to do this if you use a multi-tasking operating system, like BasicX.

### Main Loop

The main program consists of one big "do loop," which means that it will repeat all of the commands within the loop forever — or until reset. The variables that are passed to the motor "task" are generated within the main "do loop."

### Actions

Within the loop, the program sets up the four different motor "actions" — 0 to 3. The four actions are dependent on what the object or "enemy" sensors see:

**Action "0"** — No enemy is in sight, so just rotate to the right. This action is followed until something is detected.

**Action "1"** — Only the right IR sensor sees something, so veer right. Do this until a different action is needed.

**Action "2"** — Only the left IR sensor sees

something, so veer left. Do this until a different action is needed.

**Action "3"** — Both IR sensors see something. Assume it's the enemy. Go straight ahead.

The assumption is made that, when both sensors see something, the enemy robot is straight ahead. The object of the Sumo challenge is to find the enemy first, then push it off the ring.

### Priorities

The next part of the program takes precedence.

The white line — or the ring boundary — sensors are the most important. When the sumo is close to the edge, it has to move away or it will fall off.

Once the boundary is detected with the line sensors, the motor "action" is overridden. The motors are both told to move backward for two seconds. If no boundary is detected, then the computer skips over the line detection part.

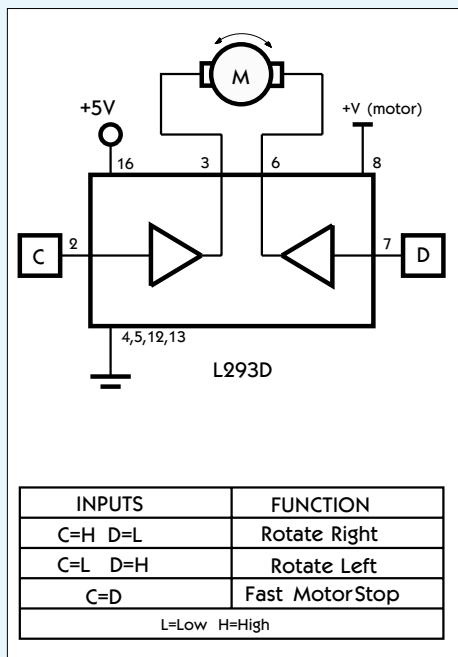
That is basically it. The loop repeats from this point on.

### Debugging Help

The only other thing that is in the main program loop is the "debug.print" command, which is used for debugging your robot's control program. This command prints the value of the "action" variable on the computer screen, which is useful if the robot is doing strange things.



## A Multi Function Robot — Part 4 <<<



**Figure 11.** The diagram shows a simplified hook-up of half of the L293 H-bridge driver chip and the logic necessary to make it work.

program just won't work the same way. The ARM, which will be introduced in a future article, needs a controller capable of running at least five R/C servos, simultaneously.

In the case of the ARM, the multi-tasking ability of the BX-24 is essential for smooth operation without resorting to an external servo co-processor.

For those of you are not familiar with programming, I will try to illustrate the difference between multi-tasking and non-multi-tasking software. Just imagine that you have two arms and two legs. Okay, that wasn't too hard. Now, imagine going for a jog. Each arm and each leg has a simultaneous function to perform and each function or task has to be simultaneous.

That is exactly what a multi-tasking program does; it allows for simultaneous, multiple operations. With a single-tasking controller, you can still move an arm or a leg, but only one of them can be

moved at any given time. It would be pretty hard to go jogging by moving one limb at a time — try it.

## Another Flippin' Mod

It looks like I run out of writing space faster than a speeding bullet. I still have so much more to show you, but we have to move on and prepare for the next addition to the C. E. Robot.

Next month, we're going to flip over the "Flipper" add-on and prepare for some extreme robotics. It's time to exterminate some ants! **SV**

John Myszkowski has worked in the area of electronics and mechanical design in the industrial automation and automotive industry for over 20 years and loves tinkering. He can be reached through Email at [john@myszkowski.net](mailto:john@myszkowski.net)

## References

### Books:

- *Building Robot Drive Trains*  
Michael Owings and Dennis Clark  
ISBN 0-07-140850-9  
I found this book to be just about the most useful reference for my purposes.
- *Build Your Own Robot*  
Karl Lunt  
ISBN 1-56881-102-0
- *Junkbots, Bugbots, & Bots on Wheels*  
Dave Hrynkiw and Mark W. Tilden  
ISBN 0-07-222601-3

### Supplier and Related Information Websites:

[www.cuttingedgeprojects.com](http://www.cuttingedgeprojects.com)  
Support page for all the Cutting Edge projects — past, present and future.

[www.netmedia.com](http://www.netmedia.com)  
Makers of the Basic-X24.

[www.novarobotics.com](http://www.novarobotics.com)  
These people will supply you with the ready-to-use Cutting Edge components.

### [www.1sorc.com](http://www.1sorc.com)

Sumo11 boards, kits, expansions, and the CMUcam.

### [www.basicx.com](http://www.basicx.com)

This one is self-explanatory.

### [www.robotgames.ca](http://www.robotgames.ca)

Sumo, mini-sumo, walkers, BEAM robotics information, and competitions.

### [www.robotgames.com](http://www.robotgames.com)

Sumo, mini-sumo, walkers, general robotics information, and competitions.

### [www.solarbotics.com](http://www.solarbotics.com)

Home of the GM2 motors, other parts, and BEAM projects.

### [www.barello.net](http://www.barello.net)

Larry Barello has an assortment of low cost, good quality controllers for sumo, mini-sumo, ANT size, and full size robots. Tons of robotics ideas and information is also available.

### [www.bugnbots.com](http://www.bugnbots.com)

Source of GM2 motors, mini-sumo robot, and BEAM kits.

### [www.hobbyengineering.com](http://www.hobbyengineering.com)

GM2 motors and other robotics components, kits, and educational projects.

### [www.junun.org](http://www.junun.org)

MK-III kits, micro and nano-sumo controllers and components.

### [www.avrfreaks.net](http://www.avrfreaks.net)

Atmel controller resource page. Development software and links, good information.

### [www.ridgesoft.com](http://www.ridgesoft.com)

Java compiler for Sumo11 and the "Handy Board."

### Yahoo User Groups:

<http://groups.yahoo.com/group/CuttingEdgeProjects>  
<http://groups.yahoo.com/group/MiniSumoMarkIII/>  
<http://groups.yahoo.com/group/Sumo11users/>  
<http://groups.yahoo.com/group/tabrobotkit>

# Designing Robots with CAD

by Gordon McComb

**B**efore building your next robot, consider drawing it all out on paper first, not with a pencil, but with a computer-aided design (CAD) program.

CAD is more than just a computer drawing program. It combines the ability to draw and edit geometric shapes with the layout precision needed for high resolution drafting. The idea behind CAD is that you can not only draw a rectangle, but you can draw a rectangle that is precisely 1" by 2" — or any other dimensions that you choose. Absolute measurements are stored with the CAD file and, when used with the appropriate printer, produce highly accurate renditions of your drawings.

Note that CAD programs are often referred to as 2D or 3D. A 2D CAD program can create a two-dimensional drawing. The layout on the drawing has height and width, but no depth. A 3D program can create a three-dimensional drawing that has height, width, and depth.

Most 3D CAD programs can render 3D shapes using complex lighting and shading options. 3D CAD is not required for producing basic robot layouts, but it is helpful if you wish to visualize — or model — the robot in its finished form. 3D rendering is helpful in testing a design; in addition to visualizing the robot

itself, you can model its environment, such as the hallways and rooms of a house or even the walls of a maze. Even with rudimentary positioning, you can determine if your design is workable in its intended environment. For example, you might find out that the new R2-D2 robot you're working on is too large to turn around in the doorway to your bedroom.

In this month's "Robotics Resources," we'll take a look at a variety of 2D and 3D CAD programs that can be used to design and model robots. We'll also cover several sites that offer useful utilities and ready-made libraries that you can use with your CAD program.

## Lots of Choices

AutoCad, from Autodesk, is

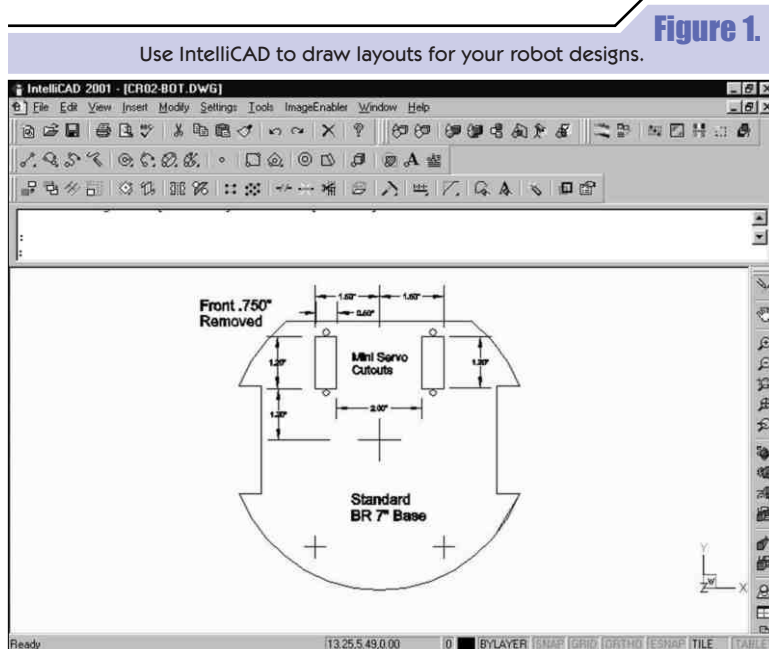
perhaps the best known CAD program and it is used by thousands of engineers and designers worldwide. As with any commercial CAD program, AutoCad is frightfully expensive. (Autodesk makes a lower-cost, entry-level version — priced at \$49.00 — named QuickCAD.) If you're a student, you may qualify for a student discount, but even so, prices may be higher than what you'd like to spend for a tool that will see only occasional use in the robotics lab.

An alternative is a free or low-cost CAD program; by low-cost, I mean a program that costs \$250.00 or less. That's actually fairly cheap in CAD software terms! Several such programs are available for download from the Internet. While they may not compare with high-end commercial products like

AutoCad, they are more than sufficient for our applications. For example, one of the leaders in low-cost CAD programs is IntelliCAD, a quasi-open source project by the IntelliCAD Technology Consortium. IntelliCAD is located at [www.intellicad.org](http://www.intellicad.org)

(Note that open source doesn't strictly mean free. It means that programmers join forces to produce software that is made available to the public. Fees can be charged for open source software.)

Viewed in brief, IntelliCAD is something





## Some Honorable Mentions

(again, an incomplete list)

AC3D — [www.ac3d.org](http://www.ac3d.org)

Alibra — [www.alibre.com](http://www.alibre.com)

CAD X11, GTWorks —

[www.graytechsoftware.com](http://www.graytechsoftware.com)

DeltaCad — [www.dcad.com](http://www.dcad.com)

DesignCAD 3D Max — [www.upperspace.com](http://www.upperspace.com)

freeCAD — [www.askoh.com](http://www.askoh.com)

GenericCADD — [www.genericcadd.com](http://www.genericcadd.com)

Graphite — [www.ashlar-vellum.com](http://www.ashlar-vellum.com)

MicroStation — [www.bentley.com](http://www.bentley.com)

QCAD — [www.ribbonsoft.com/qcad.html](http://www.ribbonsoft.com/qcad.html)

SmartDraw — [www.smartdraw.com](http://www.smartdraw.com)

VersaCAD — [www.versacad.com](http://www.versacad.com)

of an AutoCad “clone,” though this is an unfair description to both programs. Both IntelliCAD and AutoCad offer features that are unique to each program. Both use the same file format (DWG) and IntelliCAD can also run many AutoCad add-in programs and LISP “macros” (some conversion may be necessary). Like AutoCad, IntelliCAD supports both menu-driven and command-line prompts.

I’ll let the IntelliCAD website and documentation speak for itself and cut straight to using this tool to build robot layouts. Do note that other CAD programs operate in about the same way and offer the same basic tools. Figure 1 shows IntelliCAD with a simple drill and cut template. You can see that the program supports hundreds of on-screen short-cut buttons not discussed here and that, for this example, I’m using the CADopia branded version; the appearance of your version may be different.

## Basic CAD Functionality

Typical of CAD programs, IntelliCAD requires something of a steep learning curve to discover how to use its

features, but basically — and for our purposes — the functionality of the program can be narrowed down to the following:

**Drawing setup.** Here, you define the drawing size and drawing scales (e.g., 1:1, 1:12, etc.), unit of measurement, grid size, and drawing resolution. For most robotic projects, you’ll want a 1:1 scale, a grid of 1/4” or 1/8”, and a resolution of two or three decimal places — i.e., down to the hundredths or thousandths. Pick the unit of measurement (inches, millimeters, etc.) based on convenience and habit. For layout work, a resolution of two decimal places is satisfactory.

**Drawing primitives tools.** Only a few of these are used for typical layout drawings: line (and/or polyline), circle, and rectangle. Lines are used to mark cutting layouts. A polyline is a set of lines that share at least two or more vertices; it is used whenever you want to cut out more complex shapes. Circles are typically used to denote holes for drilling. A rectangle or square is a closed polyline shape and can be produced using the line, polyline, or rectangle tool.

**Editing/sizing tools.** You can adjust the size and shape of the primitives by using the mouse or by

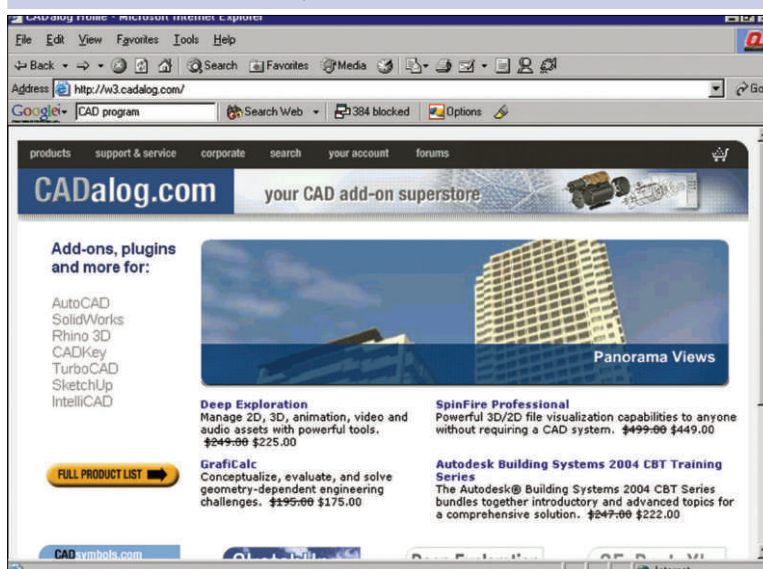
entering values at the command-line prompt. The mouse is good for “eye balling” the design, but the command-line entry of values is handy when you need accurate placement.

**File saving/printing.** Once you are done with the drawing, you can save it for future use or print it out. Any supported printer will do, such as a laser or ink jet printer. CAD programs don’t have to be used with pen plotters any more, as long as the drawing will fit onto the paper you’ve loaded into the printer. When using a laser or ink jet printer, make some sample shapes of known sizes, then measure the resulting printout. You may need to make fine adjustments in the printing setup to compensate for minor variations in sizing. The manual for the CAD program you are using will explain how to do this, if the program supports this feature.

Drawings are placed on a work-plane. With 2D CAD, a simple X and Y coordinate system is used to denote the origin of the drawing. With IntelliCAD — and most CAD programs — the origin is the lower-left corner of the drawing and is denoted as 0,0. The first digit is the X axis; the second digit is the Y axis. The values are in inches, millimeters, or another unit of measurement that you have selected.

Figure 2.

At the CADalog website, you can purchase the popular CAD program, as well as utilities and libraries.



## Benefits of CAD

Using a CAD program to create robot parts — such as cutting and drilling layouts — brings several benefits:

**Accuracy.** With CAD, it’s relatively easy to draw shapes with the exact size you want — no more guessing. You can precisely control both the size of lines, circles, and other primitives and their spacing in relation to one another. This can be done using the sizing and dimensioning tools and with snaps — a

feature supported by IntelliCAD and most CAD programs. Snaps force drawing elements to conform to known sizes and boundaries.

**Drawing automation.** If, for example, you need to produce a series of 20 holes around the circumference of a 6" circle, tools provided by the CAD program make this easy. CAD programs support automation in different ways. Some let you write or record macros for repetitive tasks. Others offer features — such as entity copying — where you first select the drawing element you want to reproduce and then indicate the number of copies and their distribution over the drawing area.

**Editability.** Designs can be readily and quickly altered, in case you need to make adjustments. This is sometimes necessary as you refine a design to make it better. While some refinements can be made "on the fly" as you work with the finished robot, you may also wish to go back to the original design, make changes, and start over again. The edited version is also useful if you are sharing your designs with others.

**Tooling.** A fourth benefit applies if you own or have access to a computer-controlled mill or router. A drawing you produce with the CAD program can be used directly to produce the layout on the mill or router. This requires the CAD program to support whatever file format is required of the mill/router tool. Most computer-controlled mills and router software can read DXF files, which is a commonly supported file format of 2D CAD programs.

## Other Free/Low-Cost CAD Options

IntelliCAD is only one of several free or low-cost CAD programs. Most are available for the PC, though versions for Linux and Macintosh

are also available. Some are "lite" versions of higher-cost commercial applications, while others are shareware (pay if you use) or time- or feature-limited (but otherwise functional) demos.

Several free and low-cost CAD alternatives are listed in the CAD Sources section. The list is by no means exhaustive and you should be aware that some of the programs — and even websites — may come and go. Always check [www.google.com](http://www.google.com) and other search engines for current leads.

## CAD Sources

Unless otherwise noted, CAD programs listed in the following section are designed to run under Microsoft Windows (typically Windows 98 or later). General CAD libraries in DXF, DWG, SAT, and other formats can be used under any operating system.

### AutoDesk

[www.autocad.com](http://www.autocad.com)

Any discussion of computer aided design software starts here, with AutoCad. This program is the industry leader that the competition mimics — at least in features. AutoCad is fairly expensive, with a full system starting at about \$1,000.00. The program is most commonly found in academic

and commercial settings, rather than among home-based amateur robot builders. If you're a student, you can get an attractive discount. QuickCAD, an entry-level version with basic features, is also available.

### Cadalog

[www.cadalog.com](http://www.cadalog.com)

Cadalog offers many add-ins and libraries for popular CAD programs, including AutoCad, SolidWorks, Rhino, CADKey, and Sketchup.

### CAD Depot

[www.caddepot.com](http://www.caddepot.com)

CAD Depot is an online shareware repository for CAD add-ins and libraries. Downloads are by category, such as CAD utilities, CAD/CAM (computer aided design/computer aided manufacturing), and AutoDesk.

### CADKey

[www.cadkey.com](http://www.cadkey.com)

Now renamed KeyCreator, this 3D CAD program is among the oldest in the industry. The program is intended mainly for higher-end commercial use.

### Cadopia IntelliCAD

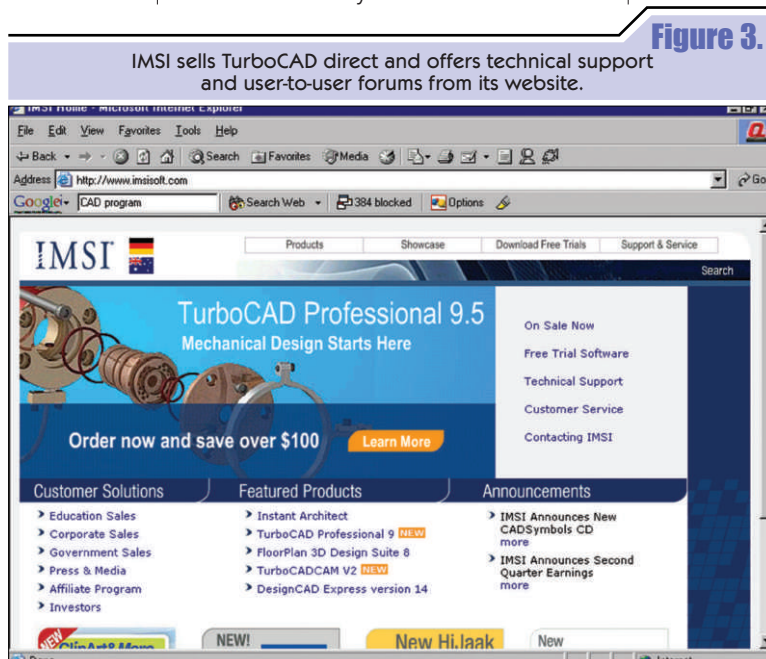
[www.cadopia.com](http://www.cadopia.com)

Cadopia is one of the IntelliCAD family of products (see also IntelliCAD) available as a free demo or fully functional download, in addition to the retail box with manual. Price for the download version is \$249.00, with discounts to educational institutions.

### CAD Standard

[www.cadstd.com](http://www.cadstd.com)

CAD Standard offers both CAD Standard Lite (free for download) and CAD Standard Pro fully-functional and low-cost computer aided drawing programs. Cost for a single-user is \$25.00. Customer support is available through their website.





## IntelliCAD

[www.intellicad.org](http://www.intellicad.org)

IntelliCAD is a kind of open source software designed by a consortium of private developers. The basic IntelliCAD package is \$249.00, with higher prices charged to developers who want to customize the program for their needs.

## IronCAD

[www.ironcad.com](http://www.ironcad.com)

IronCAD is a 3D design tool intended mainly for industrial and commercial applications. A primary feature of the program is a set of editing tools to make alterations easier.

## Open Cascade

[www.opencascade.com](http://www.opencascade.com)

Open Cascade is an unusual collection of open source CAD and engineering tools, mostly for the scientific community, which may be ideal for the college or university environment. Most of the tools are in C++ libraries and many can be downloaded for testing and evaluating.

## TigerCAD

[www.tigercad.com](http://www.tigercad.com)

TigerCAD is a low-cost 2D CAD program that is available in several versions: free

demo, limited-use evaluation, and full. The price of the full version is \$99.00.

## TurboCAD

[www.imsisoft.com](http://www.imsisoft.com)

Now in its ninth version, TurboCAD is one of the most popular "AutoCad alternatives" available. The program is available in a number of versions, from an under-\$100.00 limited edition to a professional-level version that retails for \$695.00. For those just starting out, TurboCAD Deluxe (about \$99.00) provides all of the rudimentary 2D/3D features that are most commonly needed in robotics design.

Support is available through the website and user groups.

## PowerCAD (open source)

[sourceforge.net/projects/powercad](http://sourceforge.net/projects/powercad)

PowerCAD is an open source development program that is aimed at the creation of a versatile CAD tool for POSIX-compatible operating systems. The group is not highly active, but the results seem promising so far.

## PowerCAD (commercial)

[www.givemepower.com](http://www.givemepower.com)

Apparently no relation to the open source PowerCAD, this version is available for Windows desktop, CE, and Tablet operating systems. Price for the Pro edition is \$495.00. The Classic edition, offering 2D drawing, is \$99.00.

## Rhino

[www.rhino3d.com](http://www.rhino3d.com)

Rhino is a 3D rendering tool. At \$895.00 (a student version is \$195.00), it is nevertheless "competitively priced" when compared to some of the other high-end programs, like Solidworks. Rhino touts that it is a NURBS modeling

tool; for the uninitiated, NURBS stands for Nonuniform Rational B-Splines — an industry standard tool for the representation and design of geometric shapes.

## SketchUp

[www.sketchup.com](http://www.sketchup.com)

SketchUp is not a traditional CAD program, but rather a quick prototyping tool for developing three-dimensional drawings. It is useful for visualizing the look of finished robots and the sketches can be exported in standard DXF format (allowing for interchange with conventional CAD programs).

Similarly, the program allows the importing of DXF files, so you can draw the basic bot in some other CAD program, then import it into SketchUp for modeling. The price is \$475.00 for download and it is available for Windows or Macintosh.

## Solidworks

[www.solidworks.com](http://www.solidworks.com)

Solidworks is among the top 3D rendering programs. (Actually, it is a family of programs.) Anything but cheap, this program is designed to accurately render any three-dimensional drawing you can imagine. Features include exploded views, slices, and a variety of analysis tools. Plug-ins and accessory programs include an animator and a document collaboration manager.

## vDraft

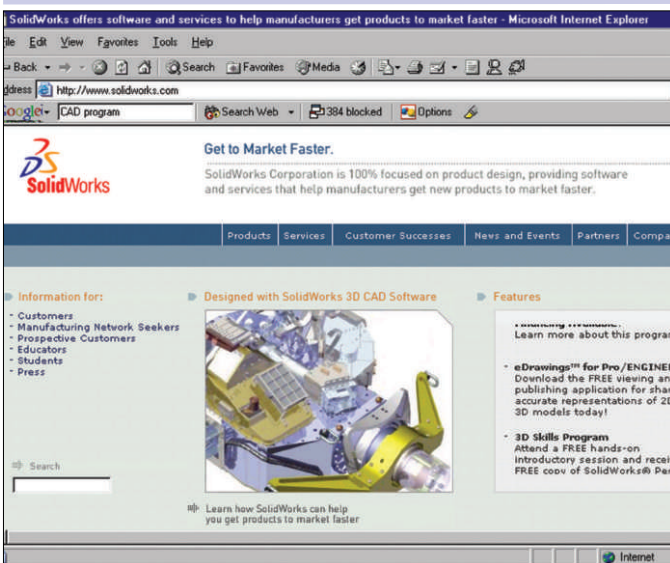
[www.softsource.com](http://www.softsource.com)

vDraft is available in demo and full (\$250.00, download) versions. It is a computer-aided design tool with a special emphasis on AutoCad compatibility.

The company also offers some low-cost browser plug-ins, including an AutoCad/DXF plug-in that allows viewing and printing of AutoCad and DXF based drawings over intranets and the Internet. **SV**

Gordon McComb can be reached at  
[robots@robotoid.com](mailto:robots@robotoid.com)

**Figure 4.** One of the premier 3D modeling programs is Solidworks, popular at engineering schools.



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# APPETIZER

## Artificial Stupidity, Perception, and the Rubik's Cube

by James Antonakos

Years ago, I read a funny and insightful article in *Omni Magazine*. The author used the expression "artificial stupidity" to provide a humorous way of looking at the world of artificial intelligence (AI) and the pitfalls of human intelligence. To me, this expression has always meant that we learn just as much from our mistakes as we do from our successes. A colleague keeps a quote on her wall that also speaks volumes: "Artificial intelligence is no match for human stupidity." Well, that may be true. We plug things in backwards. We skip some steps when following instructions because, "We know what we are doing." We forget. We do not think of all the possibilities. We overlook the obvious.

So, how does one sit down and create AI software for an application? How can we make the mouse solve the maze, the robot drive over the bridge, or the chess piece trap the king? There are well-established algorithms for solving particular tasks and several programming languages are devoted to AI software development, but a large amount of creativity is also required. The ability to break a complex task down into smaller, simpler tasks, understanding information (data), knowing different ways of representing and storing information, and having the ability to apply concepts to actual results (the hardware gets built or the software gets written) are also good skills to possess.

When I developed a one-hour lecture on AI for a group of high school students, I titled it "Artificial Stupidity"

to get them interested. They seemed to like the expression, so I kept using it, but, to show them that I did not coin that term myself, I also showed them a copy of the *Omni* article. Then I explained the obstacle course of decisions I had to make while trying to track down a copy of the article. I had long since misplaced the magazine containing it, did not know the author's name, and could not even narrow down the publication date to less than a 10-year window. The Internet was not, at that time, the vast information warehouse it is today and I did not even use it during my search.

Instead, I went to my college library and did a search. No luck. The librarians directed me to the local central library facility. A nice woman helped me and, within minutes, she had searched their database and found over 6,000 matches for "artificial" and "stupidity." All this meant was that there were 6,000 documents that contained both of the keywords, but not necessarily right next to each other.

I asked her to limit the search to articles published before 1990. Now, there were only several hundred matches. When "periodical" was added to the search, the list shortened to 22 matches. A quick scan of these revealed the *Omni* magazine entry. For those interested, the author's last name is Ferris. That should be enough information to start an intelligent search.

This story serves to illustrate the principle that intelligent decisions must be used to guide a solution towards its

goal. My goal was to get a copy of the article. We expect the same results from an AI application. It will have a goal and a set of rules that guide its decision making in pursuit of the goal.

Here is something I do with my students when I want to make them aware of how important it is to know the information you are working with and how its representation affects its use. I go from student to student in the class, having each student randomly say "zero" or "one" and I record the 0s and 1s on the board. Then I tell them to examine the string of 1s and 0s. A sample string follows. Only spend a few seconds looking the string over:

0 1 1 0 1 0 1 1 0 1 1 1 0 0 1 0 0 1 0 1

Then I tell them to close their eyes and try to repeat the string. Can you do it? My students always have difficulty. They can usually get the first five to seven bits right, but then they fall apart. I, of course, have a trick up my sleeve. Without having looked at the string since I wrote it on the board, I begin repeating the entire string, correctly — multiple times. I even do it five, 10, and even 30 minutes into my lecture.

What is the trick? Unlike the students, who are trying to memorize a 20-bit string of 1s and 0s, I am only memorizing a five symbol string of hexadecimal characters.

In fact, this 20-bit string is equivalent to the 6B725 hexadecimal. So, all I have to remember is 6B725,



not 01101011011100100101. I convert the hex symbols back into their four-bit patterns as I repeat the string. Perhaps this is why phone numbers are only seven digits long. Our short term memory can not remember too many things at once for very long, but this example illustrates the important point that there are different ways to look at the same information. One way of looking at it may lead to an insight, a time-saving efficiency, or just a simpler way to represent something.

So, in our quest to become artificially stupid and, thus, artificially intelligent, what is next? We have just seen that how we organize or interpret our information is one factor to consider. Another factor is memory — or lack of it. I do not want to open a philosophical can of worms regarding the nature of intelligence, but there are many types of intelligent applications that make use of memory and would be doomed without it. Here is one I do with my students: I ask one of them to pick a number between 1 and 1,024. Then I begin trying to guess the number. Is it six? No. Is it 159? No. Is it 500? No. Is it six?

Here we have the problem of a lack of memory. If I do not remember the choices I have already made, I am doomed to repeat them. The mouse endlessly circles around in the maze.

I try the guessing game again, only, this time, I choose my numbers carefully, according to a simple rule. If my guess is not correct, I ask the student to tell me “higher” or “lower.” I tell my students that I can guess the number in 10 tries or less.

My first guess is 512. If the student says “lower,” my next guess will

be 256. If the student says “higher,” my next guess will be 768. With every guess, half of the remaining numbers is eliminated. So, by remembering previous choices and using a little thought during the comparisons, we end up with a quick way to guess the missing number. The students are always surprised when I tell them they can guess a number between 1 and 1,000,000 with 20 or fewer guesses or a number between 1 and 4,000,000,000 with 32 or fewer guesses.

Now and then, there is a student who is familiar with powers of two and understands how the maximum number of guesses relates to the numbers used.

This efficient way of guessing also applies to searching for one datum in a large group of data. Depending on the data structure used to store it, we will have efficient (accomplished using a binary tree) and inefficient (linked list or array) search techniques.

Recall that an AI application has a goal it seeks to reach by using its internal rules. The goal might be finding the path through a maze, navigating a robot over an obstacle, solving a puzzle, or choosing the best move in a chess game. Here is a simple example of a goal-oriented application: In Figure 1 below, eight numbered squares are arranged as a three-by-three grid of tiles, with one blank space in the grid. Any tile bordering on the blank space can move into it.

You can think of moving the numbered tiles around or you can think of moving the blank space around. That is an interesting way to look at the problem, isn't it? If you could hold the eight-tile puzzle in your hand and use your finger to push the “7” tile down to

touch the “3” tile, you would, naturally, feel that you moved a tile from one place to another. Well, it is just as correct to say you moved the blank space up one row in the puzzle. It may even turn out that it is easier to write the code for the application with this alternate interpretation in mind. It pays to think

differently about a solution, if you can.

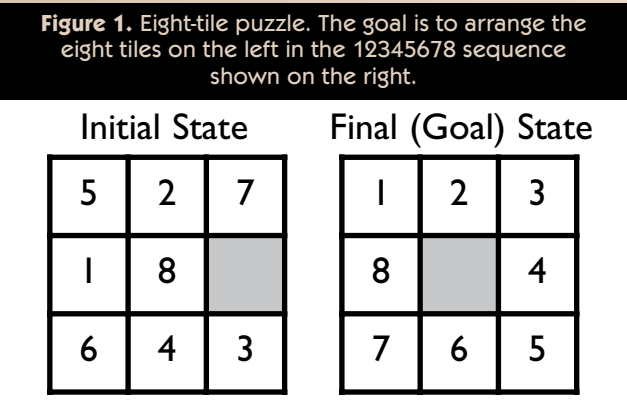
Choosing the direction to move the blank (or a tile) is done by using a heuristic. This is a method used to measure the state of the system in order to make a decision. A heuristic for the eight-tile puzzle might produce a number based on the tile positions. The value of the number guides the choices concerning the direction to make moves. The same type of approach is used to evaluate the pieces on a chess board or the path through a maze.

How do you come up with a heuristic? You just try something. A little creativity and imagination is required, along with some possibly wishful, logical thinking. You write a simple equation to calculate a number, based on all the input parameters, then make your decision based on the number. If you have a poor heuristic, the system does not move closer to the goal. The numbers slide around inside the puzzle, never getting any closer to the desired sequence. The robot goes off the cliff. The white queen sacrifices herself in exchange for a black pawn.

Oops — bad heuristic. More experimentation is required. You make a change and try again.

Note that it may not be good enough for the heuristic to just find a solution. It might need to find the best solution. Can you ever know if you have the best heuristic for the job? That is a hard question to answer, but I lean towards, “No.” I think it is easier to know if you have a heuristic that works instead of one that does not work. If your heuristic for the eight-tile puzzle solves the puzzle in an average of five moves and a friend's heuristic typically requires 12 moves, it is clear that your heuristic is working pretty well.

Here is one heuristic for the eight-tile puzzle that seems to work well. For each tile position, subtract the current tile value from the desired tile value. For example, referring to Figure 1, we look at the upper left corner tile position and subtract the “5” that is currently there and the “1” that we want to be there. The difference is four. In the next tile position, we subtract “2” and “2” and get a difference of zero because the “2” tile



is in its correct position. We do this for every tile position and add up all the differences. Technically speaking, we use the absolute value of the difference so that negative differences do not skew the results. The lower the sum, the better, because that indicates that one or more tiles may be in position. A sum of zero means the goal state has been reached. (All eight differences would total zero because each tile is in its correct position.)

Well, deep inside your mind, somewhere in a sea of neurons and chemicals, is the spark that may create the cascade of synaptic transmissions that will grow into the thought that leads to the creation of a better heuristic, but where does the spark come from? Have you ever worked on a problem — I mean really worked on it for hours — without getting anywhere with it? Then, maybe after a break for some fresh air or a nice shower, you try again.

Suddenly, your mind gets that funny feeling; you are on to something. You do not know what is coming next, but you feel that you are on the right track and then, in rapid succession, the unknowns become known. You know what equation to use next; it is all falling into place. Finally, when you get to the answer, it is as if you already knew it. It makes sense. You are confident that it is correct, even though you have never solved the problem before! This is where perception has served you well.

The moment of perception is the spark that ignites the neuronal chain reaction and, naturally, it is you that chooses the moment of perception. If not you, then who else is choosing your moment of perception? Is it just a random neuron firing that happened, by chance, to lead to the solution? Not very likely. Your thought created a reality. Your thought led to the solution. Your handwritten solution on a piece of paper is the reality that your thought created. How does the thought originate? How does the spark ignite? What triggers your perception? Is it caused by some multiple-tile puzzle in your brain, with the tiles shifting positions, combining basic facts you know into complex patterns that make sense logically or do not?

Of course, sometimes we just guess. We take a stab at it and hope for the best. This is not a very scientific way of pursuing a solution, but, sometimes, it works, doesn't it? People win the lottery with guesses. I cannot imagine Deep Blue — IBM's chess-playing supercomputer — making guesses during a game. I imagine that there is a decision tree for every possible move and its countermoves, several layers deep, constantly being trimmed and pruned as the game goes on. If we are looking to mimic the intelligence of humans, however, guessing is part of the game; it adds a bit of randomness to the equation. Unfortunately, we have no way of calculating random numbers. Certainly, we can generate seemingly random strings of numbers with billions or more combinations, but the numbers are still being generated using an orderly process. Pick a 32-bit prime number. Start with a 64-bit seed value and divide it by the prime number. Swap the 32-bit quotient and remainder and you have your new 64-bit pseudo (fake) random number. Division is surely not a random process, hence there is no real randomness in the formula. Now, if every computing system on the planet used temperature sensors, coupled with gravitational, humidity, pressure, and probably even *Star Trek* subspace field activity sensors, all of those sensor readings

may combine into a truly random number. However, anyone who has viewed a Mandelbrot image or played with a Chaos equation or two knows that we sure can do a good job of simulating randomness.

So, there you have it. Is our fallible human intelligence — sometimes prone to guesswork — really a match for artificial intelligence? Let me finish by repeating a story I heard from an old professor of mine, who had an interesting conversation companion on a return flight from a vacation. The man told my professor the following story:

The mathematics department at a large university had a single opening for a new teaching position. They wanted to hire one student from their current class. It was decided that an exam would be given and the student who performed the best on the exam would be given the job. When the day of the exam arrived, all of the students, except one, showed up on time. After some explanations, the exam was handed out and the students began their work. A short time later, the remaining student arrived, apologizing for being late. He was quietly handed an exam.

The next day, the student who had arrived late was waiting in his apartment when the head of the mathematics department knocked on

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his door. The student was instantly depressed, coming to the conclusion that he performed poorly on his exam due to his late start. He assumed that the head of the department wanted to pass on the bad news personally. He opened the door and was surprised to see a large smile on the chairman's face. Confused, he asked what was going on.

The department chairman congratulated the student on his performance on the exam. He was being offered the job. The student became even more confused. How can that be, he wondered, knowing that he did not even answer one of the questions completely. The department chairman explained that, due to his late arrival, the student did not hear the initial instructions given to the other students. They were told that two of the questions on the exam were open problems — problems that had not yet been solved by anyone, in spite of years of attempts.

*The student had solved one of the problems.*

Without the burden of knowing that his task may have been impossible — that many others had tried and failed

## About the Author

James Antonakos is a Professor in the Departments of Electrical Engineering Technology and Computer Studies at Broome Community College. He has over 27 years of experience developing software and designing digital and analog circuitry, in addition to having written numerous textbooks on microprocessors, programming, and microcomputer systems. You may reach him at [antonakos\\_j@sunybroome.edu](mailto:antonakos_j@sunybroome.edu) or visit his website at [www.sunybroome.edu/~antonakos\\_j](http://www.sunybroome.edu/~antonakos_j)

before him — he simply went ahead and applied his knowledge, skills, and perception into a legitimate solution, attacking the problem like he would any other problem.

For me, this is an uplifting story. We do not know the great things we are capable of. I, for one, would be happy to solve the Rubik's Cube puzzle just once in my lifetime. My children can do it; I cannot. I know it is impossible — there are just too many combinations — but I want to try. **SV**

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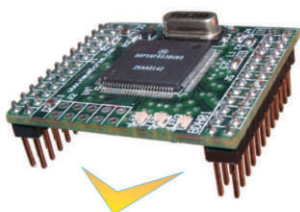


**TiniPod™**

- **SCI w/RS-232**
- **SPI**
- **CANBus**
- **6 PWM**
- **6 Timers**
- **3 LED's**
- **64K Flash**
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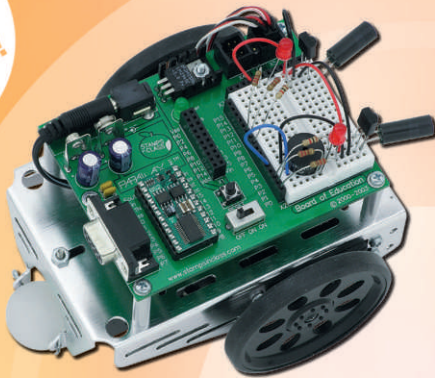
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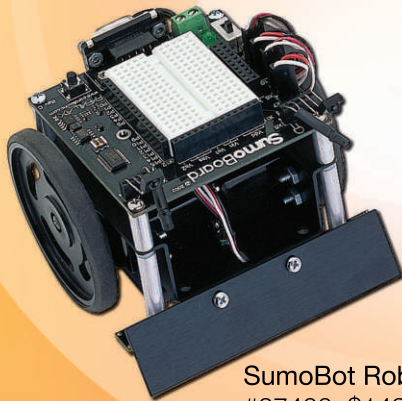
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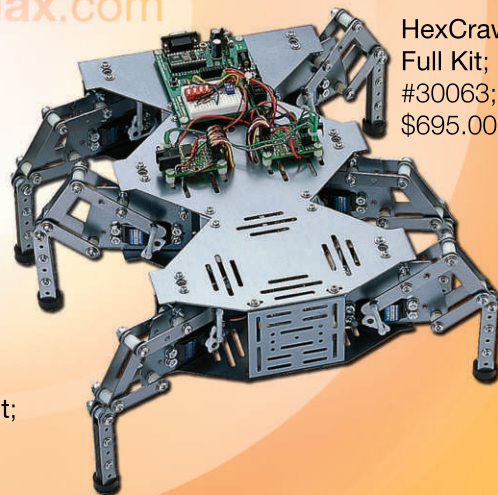
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